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## INDUSTRIAL SURVEY OF ELECTRONIC PACKAGING

by

J. L. Easterday  
D. A. Kaiser  
C. H. Burley

November 1966

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## **ABSTRACT**

This report reviews a survey of 17 industries on current techniques for packaging electronic equipment. Subjects covered include module configuration, package configuration, package housing, interconnection techniques, and potting compounds. The specific reports of each brief interview are contained in Appendix A of the report. Appendix B updates a previous bibliography for electronic packaging published in RSIC-534, entitled "Electronic Packaging: A Bibliography," dated March 1966. A listing of companies visited is included in the Foreword.

Information provided is a review of electronic packaging techniques ranging from the mounting of parts (discrete or integrated circuit) to a complete "black box." Module configurations discussed include planar printed-circuit boards, "stick" modules, cordwood, mylar tapes for part mounting, and variations of these. Package configurations have been aimed at reducing the number of layers in multilayer printed-circuit boards. Techniques include book type modules interleaving printed-circuit boards, slotted guides in housings, and precompressed stacks of printed-circuit board assemblies. The package housings may be cast, dip brazed, automatically milled from solid stock, or light sheet metal covers. Many types of interconnection techniques are in use including multilayer circuitry other than conventional printed-circuit boards. Eyelets and plated-through holes are usually reinforced by filling, redundancy, etc. No great variations in potting methods were noted except for radio frequency modules. However, problems of nonuniform density were indicated.

It is apparent that no one approach is a panacea for all packaging requirements. Each piece of equipment must be analyzed (along with the manufacturer's capabilities) and the most appropriate technique selected.

## FOREWORD

This report presents the findings of visits to several electronics manufacturing companies engaged in aerospace equipment manufacture, for the purpose of discussing current and future planned packaging techniques for electronic equipment. The objective is to provide a review of practical, successful packaging techniques and approaches as they are presently utilized. This information should complement the bibliography (RSIC-534) on electronic packaging.

In addition, a very limited survey was performed to update the previous bibliography (RSIC-534).

The companies and organizations which participated in this survey are as follows.

Brown Engineering Company, Huntsville, Alabama  
Cubic Corporation, San Diego, California  
Douglas Aircraft Company, Santa Monica, California  
General Dynamics/Convair Division, San Diego, California  
Honeywell, Incorporated, Aeronautical Division, St. Petersburg, Florida  
Hughes Aircraft Company, Culver City, California  
Jet Propulsion Laboratory, Pasadena, California  
Ling-Temco-Vought Electrosystems, Incorporated, Garland, Texas  
Major West Coast Manufacturer  
Motorola Aerospace Corporation, Phoenix, Arizona  
National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland  
North American Aviation, Space and Information Division, Downey, California  
Philco Western Development Laboratory, Palo Alto, California  
Radiation, Incorporated, Melbourne, Florida  
Sandia Corporation, Albuquerque, New Mexico  
Space Craft, Incorporated, Huntsville, Alabama  
Texas Instruments/Apparatus Division, Dallas, Texas

The authors wish to express their appreciation to these companies for their cooperation in making personnel available for interviews and for supplying photographs for this report. Reports of this nature are possible only when such valuable assistance and information are made available.

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## 1. Introduction

At the request of the Astrionics Laboratory of Marshall Space Flight Center, Battelle Memorial Institute has conducted a survey of a limited number of aerospace equipment manufacturers and agencies to discuss their current techniques and theories in regard to electronic packaging. It is intended that this report should provide a technical (but not theoretical presentation or analysis) presentation of packaging methods which are successful in aerospace applications at the present time. The information is complementary to the bibliography on electronic packaging prepared under a previous contract in that it is recognized that the published literature on electronic packaging is frequently out of date or based on unproven theoretical concepts under consideration.

The information was gathered by visiting some 17\* companies actively engaged in the manufacture of electronic aerospace equipment. To achieve the widest sampling possible within the time and funds of the present effort, it was necessary to make arbitrary selections of the companies to be visited and, in fact, even the department or project office within the company. Discussion periods within each facility were generally limited to two or three hours. Thus the information presented herein can in no way be construed as representing the total philosophy or capability of any given organization. Rather, it indicates one small sampling for each organization and in some cases only one particular product line. However, it was felt that a broad sampling from many sources would provide a reasonable comprehensive picture of the many techniques and approaches being used today.

The body of this report consists of an overall summary of the survey results. Appendix A is a collection of reports on each visit which contain the details of the various techniques and approaches discussed in Paragraph 2.

In addition, a bibliography of approximately 86 articles pertaining to electronic packaging published primarily during the first six months of 1966 has been prepared and included in Appendix B. Appendix C is a bibliography of papers pertaining to visits.

\*Two additional companies were visited but they did not participate in the survey.

## 2. Review of Findings

The following discussion consists of impressions gained from the industry survey of many different types of packaging methods. While it would be highly desirable to be able to point to specific techniques as a panacea for packaging problems in electronic aerospace equipment, such is not the case. One of the statements which recurred most often among the various companies visited was that each particular packaging job had to be considered in the total concept of the constraints and objectives of the given project and piece of equipment in order to select the most suitable packaging technique. Most of the companies had several techniques within their competency, so it was a matter of weighing the obvious packaging considerations such as reliability, production quantity, repairability, costs, space and weight requirements, heat dissipation, radio frequency problems, mechanical environments, etc. It was also noted that the same general approaches were used by many different companies, and that many times techniques which were considered unique by the particular organization were in fact not unique at all. However, there were many significant distinctions involved in the exact procedure and technique of carrying out a given approach. These appeared to have resulted because of two factors:

- 1) Specific equipment and the related contracts sometimes imposed performance, environmental, reliability, and volumetric requirements such that the organization was called upon to develop a specific technique and ability to meet the problem.
- 2) In many cases an overall philosophy was adopted as the primary packaging objective, and the companies sought to develop their competency both in knowledge and skills to carry out that type of technique.

In these cases, successful packaging techniques have been developed, and the company is competent in them, whereas attempts at a different although perhaps satisfactory procedure would be unsuccessful because of lack of experience.

Reliability has been a strong overriding factor in the selection of many of the procedures used. Compromises of other requirements are often required and many developments have been specifically aimed toward the objective of providing the necessary inspection and ultimate reliability required for aerospace applications.

#### a. Module Configuration

Basic approaches range from the conventional planar board layouts for discrete and integrated circuit parts to developmental work on extensive networks on one monolithic chip. The planar board approach has proved to be very satisfactory when properly potted and used in a suitable housing for the environments required. The obvious disadvantage is the low density nature of this approach. Even when used for integrated circuits, the density is still relatively low with respect to modular techniques. The cordwood type modules in various modifications are considered an old standby in many companies and serve quite well for rugged structures, medium size throw away modules, intermixing of conventional and integrated circuit parts, accessibility for tests before potting, and medium density. Generally, they are considered unrepairable and limited in heat transferability. Various methods of interconnecting the parts in the cordwood module are used and seem to be more a function of the developed ability of a particular company than a direct observation that any one method is far superior to another. Some of these points will be further discussed in the section on interconnections.

Some of the variations of this technique include a rather high density packaging of flat-pack integrated circuits in a basically cordwood type fashion, the use of a multipin round connector as one base for the module (developed for a specific application where additional interface networks were required in a systems requirement), and the mounting of several cordwood modules to a daughter board which is then potted as one complete module before attachment to a mother board.

A variation of the modular planar board concept being used by many companies consists of a series of small planar boards stacked with riser wires spaced around the edge of the stack of boards to provide external connections to the next level of assembly. These wires can be brought out directly for attachment purposes or brought into a connector. This small assembly is then potted and treated as a throw away module. This approach lends itself to more mechanized production and presumably fewer mistakes than a conventional cordwood module, at some loss of density. A similar approach has used stacked integrated-circuit flat packs alone, rather than on a board, resulting in a very high density module.

There is some use of axially mounted conventional parts on planar boards which improves the density for a given board but does not appear to have any particular advantage over other types of packages.



An interesting development by many companies is the use of thin layers of mylar with etched circuitry which can be built up into several layers to function as a multilayer printed-circuit board but lacking many of the latter's disadvantages. Generally, this approach is used for small modules capable of holding 20 integrated circuits in flat packs. There are several variations of the exact procedure and final assembly configuration including an optional heat sink. However, the approach is basically versatile and relatively simple in design and assembly thus lending itself to small production runs or situations where a variety of different configurations is required rather than a number of identical digital type units. Since the layers of circuitry are built up and not permanently committed until final attachment of the parts and potting of the module, it is relatively simple and inexpensive to make changes or correct mistakes. Further, equipment has been developed to pretest the assembly before any connections are made. There is also provision for inspection of all joints. When properly designed, the resulting module requires only the connection of one integrated-circuit lead to one of the interconnecting circuit leads. This not only permits a simple visual check for correctness of design and assembly but permits more accurate, reliable, standardized production techniques for making the connections. The resulting modular package achieves relatively high density.

Another development under NASA sponsorship is the so called stick module. This approach is somewhat similar in objective to the tape circuits and should provide easier handling during production. The stick module is a molded mounting frame which holds 15 integrated circuits (or a combination with discrete parts). The parts are mounted in a planar fashion, and the connection points are brought out to terminals on the back of the stick. At this point, wiring is done by hand using coated magnet wire from point to point. The planning for this type of module has gone a step further than that for the mylar strip circuits in most instances in that the major circuit interconnections are made on the stick module thus permitting the "mother board" assembly into which the modules are connected to consist primarily of a straight line "bus wire" type of layout.

Future trends in module packaging are aimed at hybrid chip type circuits and large monolithic integrated circuits. Several companies are considering various methods for mounting and connecting a large number of chips on one basic carrier to make a high-density flat module. Both thin and thick films are under consideration. At least one company has successful prototypes of each type.

There is some diversity of opinion regarding the future of large monolithic integrated circuits but at least three of the companies visited

are working on this approach and expect to have marketable products in the near future. Although extremely high density modules will result, considerable innovation is required to make the approach practical from a cost and versatility standpoint. One of the big factors will be the degree of automation which can be achieved and the flexibility of the circuits for various applications. Good inspection techniques are required to identify the bad circuits on a given chip as is a good method for developing the required circuit with the remaining good elements. At present the major emphasis seems to be on digital arrays for memory type applications.

Most of the assemblies for high frequency application more closely resemble point-to-point wiring configurations than anything else. The one exception is some application of a cordwood type construction. Generally, the requirement of a large number of discrete components, structural rigidity, and shielding precludes some of the other packaging techniques. Modular types of approaches are used, however, generally using metal frames as the structural member of the module. Primary points of interest seem to be the techniques for developing ground planes and providing suitable shielding for the package. Of particular interest, however, is the technique used by one company of filling the radio frequency module with a "dry" potting compound so that it can be tuned under final packaging conditions before the module is actually committed to the final potting.

#### b. Package Configurations

Several very interesting package configurations, many of which look like extremely good techniques, have evolved. They have been designed in part to reduce the number of layers required in the printed-circuit boards used for interconnections, whether they be daughter or mother board in function. Perhaps the most common general approach is that of a book type configuration where two or more boards have all the external terminals along one edge and are joined at the back as in the binding of a book. Based on this general concept, many specific applications are in use. The most straightforward approach is to simply join two conventional planar boards and fold them over adjacent to each other using isolation pads or potting as desired. A refinement of this approach is to use printed cabling for the interconnection. In this technique the two board sections are made as one board with the printed cabling placed across the required interconnects and the entire circuit wave soldered at one time. The boards are then cut and folded at the printed cable flexure point. Another procedure for moderately small size packages requiring only two assembly boards

of parts is to bring the two planar boards together against a central aluminum frame. Again, this may or may not be potted as desired. This frame then serves as a module for plug-in or solder installation in a larger assembly.

For more sophisticated requirements, modules such as those described above are mounted on a printed-circuit board in a pattern fashion so that they will mesh with the modules of the opposing printed-circuit board when they are placed back to back. The attempt is to place the modules in a somewhat checkerboard fashion thus providing visual access of joints from the top of the board as well as the bottom and providing additional space on the printed-circuit board for wiring. In this scheme, the board surfaces and the tops of the modules are coated with contact cement so that when the boards are brought together for the final assembly, a rigid honeycomb type of structure is produced. This same technique is equally applicable for planar boards containing TO-5 cans as the primary element.

A different type of packaging approach is an assembly of interleaving printed-circuit boards. In a particular example of this technique, flat packs are planar mounted on  $1\frac{3}{4}$ - by 2-inch circuit boards. These boards are fastened to mother boards in a stacked arrangement and then assembled back to back by interleaving the small circuit boards similar to a variable air capacitor. It permits less complicated mother boards and does provide some degree of access to the individual printed-circuit boards for checkout and replacement. A single assembly may consist of as many as 120 of the small printed-circuit boards which plug into the mother boards. Security of the free end of the printed-circuit boards was achieved by fitting them in grooves between the connectors of the opposing mother board.

The most standard assembly technique for ruggedized packages is that of using high density planar printed-circuit cards dropped into slot guides in a sturdy container. All conductors on the printed-circuit board are brought out to the edge for connection to the mother board. Various arrangements of this approach included spring loaded slots, compression pads between the boards, and provision for compression loading either in the axial direction or in the direction of the mother board. A variation of this is to stack the printed-circuit boards (either planar, modular, or combinations) with the desired spacers and apply pressure so as to compress them firmly to the container. In this case the connections are made of hard wiring in such fashion as to permit fanning the boards open for access. The next most common ruggedized package consists of dense arrays of cordwood modules.

The previous discussion indicated a rather general desire to minimize the number of printed-circuit board layers. The book assembly approaches are generally aimed at using a one to four layer double-sided board. However, many of the other techniques use six to eleven layer boards as normal. In digital computer applications where large numbers of repetitive functions are involved, the use of a greater number of layers is not only feasible, it is virtually required for efficient volumetric packaging. In these applications, the overall packaging approach is determined in part by the decision of circuitry organization. The computer circuit might be organized on a bit approach (horizontal) or it might be organized on a functional (vertical) approach. The first instance has proved quite advantageous in the design of a housing with an integral air cooling system while the latter has been used in many applications including a large system using 30-layer printed-circuit boards for the daughter boards and 21-layer printed-circuit boards for the mother boards.

### c. Package Housing

Perhaps the most striking development in the area of package housings is the value of the magnetic-tape-controlled milling machine. Several companies have found this to be an economic method of making accurate aluminum housings for packaging electronic equipment in preference to the standard techniques of sand-cast aluminum or magnesium, investment-cast aluminum, and die casting. In most cases it seems to be superior to precision casting in cost, precision of results, and simpler inspection. This technique has proved to be almost essential in one instance where careful design to provide air cooling through chassis packaging pathways was required. Aluminum castings are used, of course, in some instances but require more inspection than the frames milled from solid block. Another technique in common use is to build up an assembly of basic parts by dip brazing to produce the approximate equivalent of a casting. This has found extensive use both in large housings which are required to meet moderate vibration requirements and in small packages for radio frequency modules.

Solid housings such as these are designed for rugged environments and may include provision for the compression mounting of the printed-circuit boards and modules within the package. In any event, some technique such as preassembly compression, bolting, or spring loading in slots is provided for vibration and shock protection.

As indicated in the discussion of modules, another approach is to pot the entire package. Generally, this results in a nonrepairable system

so the level at which complete potting is applied is usually limited. The one exception is the use of certain types of materials which can be removed for repair or replacement. When this is done, it is feasible to pot large assemblies thus reducing the requirement for an extremely stable outer housing. Thus this alternate method, which is generally limited to small packages, is based on the concept of a foam or epoxy protected circuit which requires only a light metal cover for abrasion protection and shielding. This is particularly true for some radio frequency packages and other intermediate sized packages which may be equally well defined as the module or an equipment package.

#### d. Interconnections

The only conclusion to be drawn from the survey with respect to interconnection techniques is that there are as many opinions regarding the subject as there are people in the business, and that the technical people favor the particular type of connection with which they have become most familiar and have been most successful. Certainly, success is not a criteria to be ignored, but in this instance there is no clear guidance as to the direction of future connection techniques. Perhaps the most widely used connections are wave soldering, parallel-gap welding, and reflow soldering. Probably next in line is parallel-gap soldering and hand soldering. Basically, the main argument between welding and soldering is the ability to visually inspect the joint. The argument is that welded joints cannot be adequately inspected visually whereas solder joints can. While this may be true, it should be pointed out that good solder joint inspection can be achieved only by a well trained inspector and not by the average engineer who is unfamiliar with detailed documents on the subject such as NASA's NPC200-4. In particular, there have been difficulties in inspecting solder joints created by reflow soldering. For example, gold plating on kovar leads tends to amalgamate with solder resulting in a poor solder joint which has a good visual appearance. Other developments in soldering include the design of equipment to solder up to 14 leads at one time and the use of hot gas soldering for flat packs. Not to be overlooked are cost considerations between the less expensive copper-clad boards for soldering and the nickel or kovar boards used for welding.

Problems with welding seem to stem from using a variety of materials and thicknesses of the materials coupled with limited accuracy of welding machine control. The latter is being improved steadily, and, as noted in the discussion on modules, the techniques such as mylar film circuitry which result in consistent materials and thicknesses of

materials to be welded should contribute greatly to developing reliable procedures for welds. Presently some companies are using redundant welds on many connections.

There appears to be a general distrust in plated-through holes in printed-circuit boards. In some cases the holes are filled with a "Z" wire soldered in place while in others redundant eyelets are used. Some prefer to avoid plated-through holes altogether. Two of the substitute methods consist essentially of providing a pad which is the thickness of the board so connections can be made to either side. Another approach has been to use extended eyelets as discussed below.

The majority of cordwood type modules are welded with nickel wire. The consensus seems to be that a cross-wire weld of round wire is better than one of ribbon wire and round wire. Nevertheless, a large number of modules using the latter technique as well as just plain hand soldering were observed during this survey. The most common practice appears to be that of manual wiring following a printed pattern on the insulating material.

Daughter boards were assembled to mother boards by soldering, connectors, or welding. In the case of soldering, the connections were generally wave soldered although reflow soldering was used occasionally. A technique for welding such connections was also used by several companies which consisted of providing an extended eyelet through the hole in the mother board to which the daughter board pin passed. Either an auxiliary connecting lead or a section of the mother board etched circuitry was brought to bear against the eyelet and opposed electrode welding used to connect the mother board lead, the extended eyelet, and the daughter board pin together. Termi-Point and wire-wrap are being used to some extent to give a speed advantage over hand soldering and a repairability advantage over welding, but apparently have not been accepted on a wide basis.

A wide variety of connectors are in use ranging from pressure contact springs to high insertion-force mating contacts. There is no general agreement evident as to the one method's superiority over another.

A surprisingly great amount of hard wiring is still in use. It takes place in every conceivable form from point-to-point board interconnects to preformed cabling. Many of the innovations have taken place in making connections from a printed-circuit board to a connector. Several interesting techniques have been developed which in essence are a method of bringing hard wire from a hole in the printed-circuit board around a right angle bend to a connector and potting the wiring to the back of the

connector in that state. A variation of this includes prepotting the assembly so it can be dropped on the board like a module. Generally, the wiring is potted or foamed in place to secure it. Those organizations which have used printed cabling appear to be quite enthusiastic. It offers space saving and flexibility both in basic production techniques (the folded module described previously), space and weight. When this flex cable is brought directly to connectors, it is generally potted at the back of the connector. Some of the advantages cited in addition to the space and weight are the reduced likelihood of wiring errors. Disadvantages are the lead time to prepare the cable design and the lack of flexibility when changes are required.

Some work is being performed in developing techniques for welding and soldering wire without stripping it. While there appears to be a general distrust on the part of those who have not yet investigated these techniques, it would appear that there is substantial hope for the practical development of these methods.

#### e. Potting Compounds

As in the other aspects of packaging, a wide variety of potting compounds are in use. They are, generally, some variety of epoxy, urethane foam, or Stycast 1090. The use of fillers has become quite popular, one of the most interesting being the microsphere type of filler. Some companies claim the filled epoxies provide good heat transfer while other companies claim their studies show the fillers have limited value. Some studies on potting compounds with microsphere fillers has shown the criticality of uniform temperature in the mold for the potting. If the temperature should be too high and the fluid become too viscous, there will be a nonuniform density existing in the potted module resulting in differing exothermic and heat transfer characteristics. The pressures exerted by the curing epoxies are also of great interest and have been found by many to crush glass components. Therefore, it is usually necessary to apply a conformal coating to the parts before potting them in epoxy. Another subject of concern is the temperatures created internal to the module during the curing cycle. Studies of this phenomena are also being undertaken.

Another difficulty in encapsulating modules is that encountered with using foam compounds such as urethane. It is difficult to achieve a uniform foam density. One company has approached the problem by using a dispersion plate and free foaming thus achieving a uniform density. RTV also seems to be a successful encapsulant, while one company mentioned the use of transparent seal guard to promote visual access for easier repair.

Some problems with urethane foams outgassing at critical altitude levels of 65,000 feet have been encountered. Similarly it appears that voids in potting compounds have been responsible for corona discharges and equipment failures under similar conditions. However, even in this case of foam outgassing, this opinion is not universally held.

Two departures from the usual potting and foaming procedures include the use of a "B" stage epoxy between layers of a manually assembled printed-circuit board which later cures due to pressure and the use of methyl polysiloxane as a contact adhesive for assembling modules.



## Appendix A

### IN-PLANT VISIT RESUMES

---

Appendix A is resumes of each in-plant visit made for the purpose of discussing current and immediate future electronic packaging techniques. In order to perform this function within reasonable time and cost constraints, it was necessary to make an arbitrary selection of a cross section of various types of industries and agencies. In many cases only one project office was visited or one general line of products was reviewed during the two to three hour visits at each of the companies. Therefore, the information reported herein cannot be considered indicative of the total thinking or total capability of any of the companies listed. In fact, in many instances there was not time to report all the details of the techniques or even all the unique features of approaches being used by a given office. Further, each company was instructed not to divulge any proprietary information so that everything obtained during the survey would be publishable. There is, of course, much additional work being done in future planning and development which could not be reported here.

However, it is believed that these brief broad remarks resulting from this survey provide an example comprehensive picture of the majority of the electronic packaging techniques in use at the present time.

#### 1. Brown Engineering Company, Huntsville, Alabama

Brown Engineering is actively engaged in all phases of aerospace electronic packaging. Areas of interest within the Electronics Divisions are as follows:

- 1) Properties of materials and environmental effects on materials
- 2) Discrete parts to module packaging
- 3) Microcircuit to module packaging
- 4) Interconnections--Becon Connectors.

##### a. Conformal Coating and Encapsulation

Brown is working per the Marshall Space Flight Center's specifications using HiSol 007 polyurethane for spraying. Zycon also is used as a conformal coating being applied by a proprietary method. The silicone films, such as GE 615 and Dow 184 which are optically

clear films, are used in applications requiring high voltage breakdown or resistance to oils. These films also have low peel strength, making it possible to dig out parts when repairing individual boards. Epoxy pottings are not used directly on circuits where glass component packages are involved because of difference in the coefficient of expansion: these circuits are first coated with a glass-elastomeric polyurethane to give the necessary cushion. In the original SATURN units (1964), the glass items were put in a vinyl sleeve. Brown makes use of silicone, epoxy, and high temperature urethane foams for potting and have successfully used silica-filled and beryllium oxide-filled compounds for thermal conduction. Another potting compound used by Brown is the micro-balloon (hollow glass spheres ranging from 30 to 300 microns in size) filled epoxy resin. This substance has a density of 0.78 and demonstrates a superior insulating quality due to the inherent single cell structure as compared to the multicell structure of foam.

Future plans are to use transfer molding to achieve higher reliability at lower cost. They are also considering fluidized bed coating and are working on a machine to provide uniform center coating.

#### b. Printed-Circuit Boards

Brown has standardized on kovar and pure nickel foils since these are the only materials presently qualified for welding by NASA Flight Standards. They are successfully etching kovar boards and are supplying these to Sperry Astrionics for multilayer board makeups. A technique has been developed for producing a 40- to 60-micron layer of hot solder coating on printed-circuit boards. The technique employs a wave-solder coating with a propriety follow-on process that removes excess solder and smooths the remaining solder into a thin uniform coating. When perfected, the machine will be marketed. Brown is also investigating the removal of flux residue from completed printed-circuit boards through the use of an ultrasonically actuated wave of solvents. Here, the cavitation is meant to occur only at the level of the board and not at the level of the mounted components. A heavy mass is used to damp the board as it moves through the machine.

Examples of planar board packages are shown in Figures 1 and 2.

#### c. Microelectronics

Brown is going in the direction of thick films since this method lends itself to greater utilization of monolithic chips. Presently, the thick gold film is screened directly onto a ceramic substrate and fired in an oven. The monolithic chips are attached face up to the

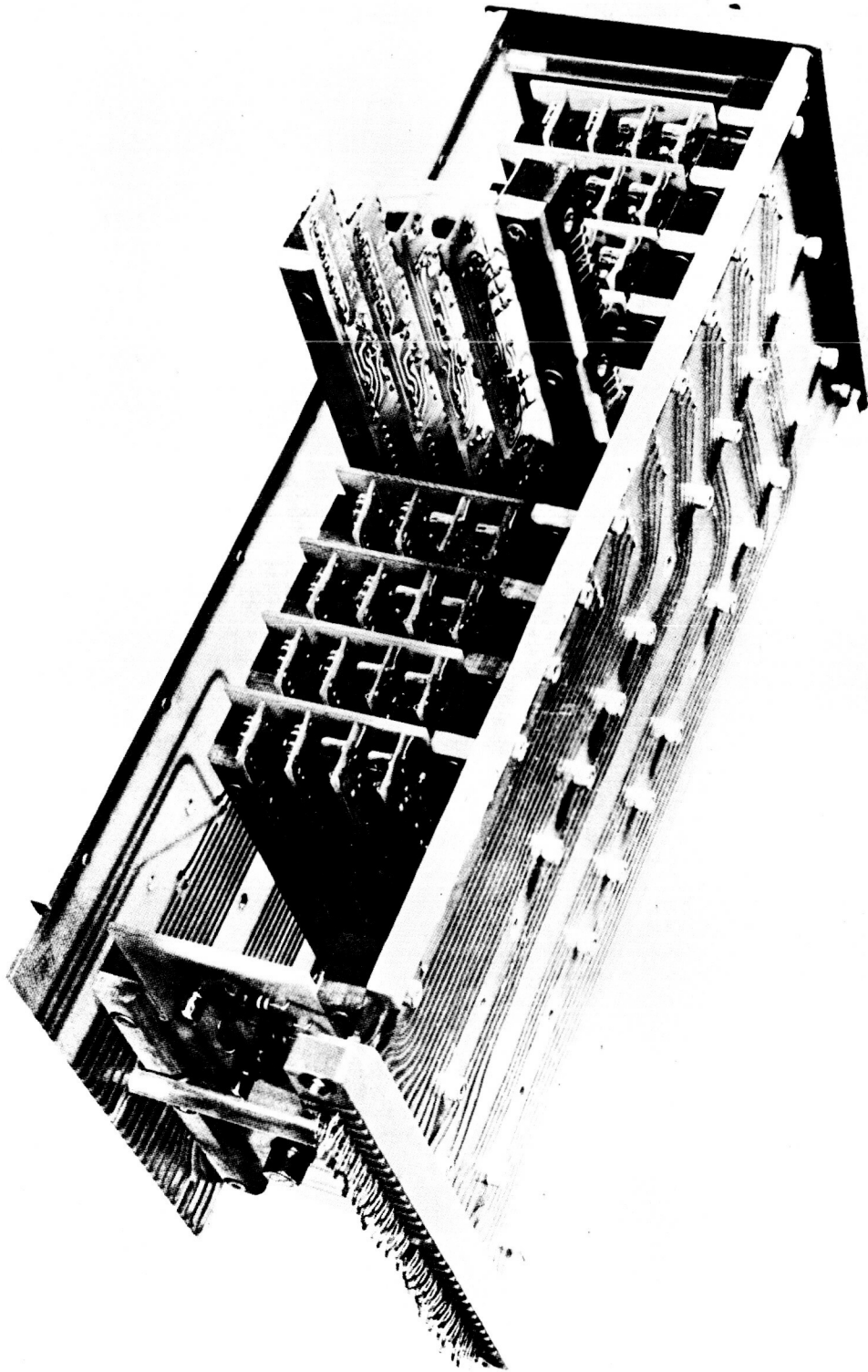


Figure 1. Binary Counter

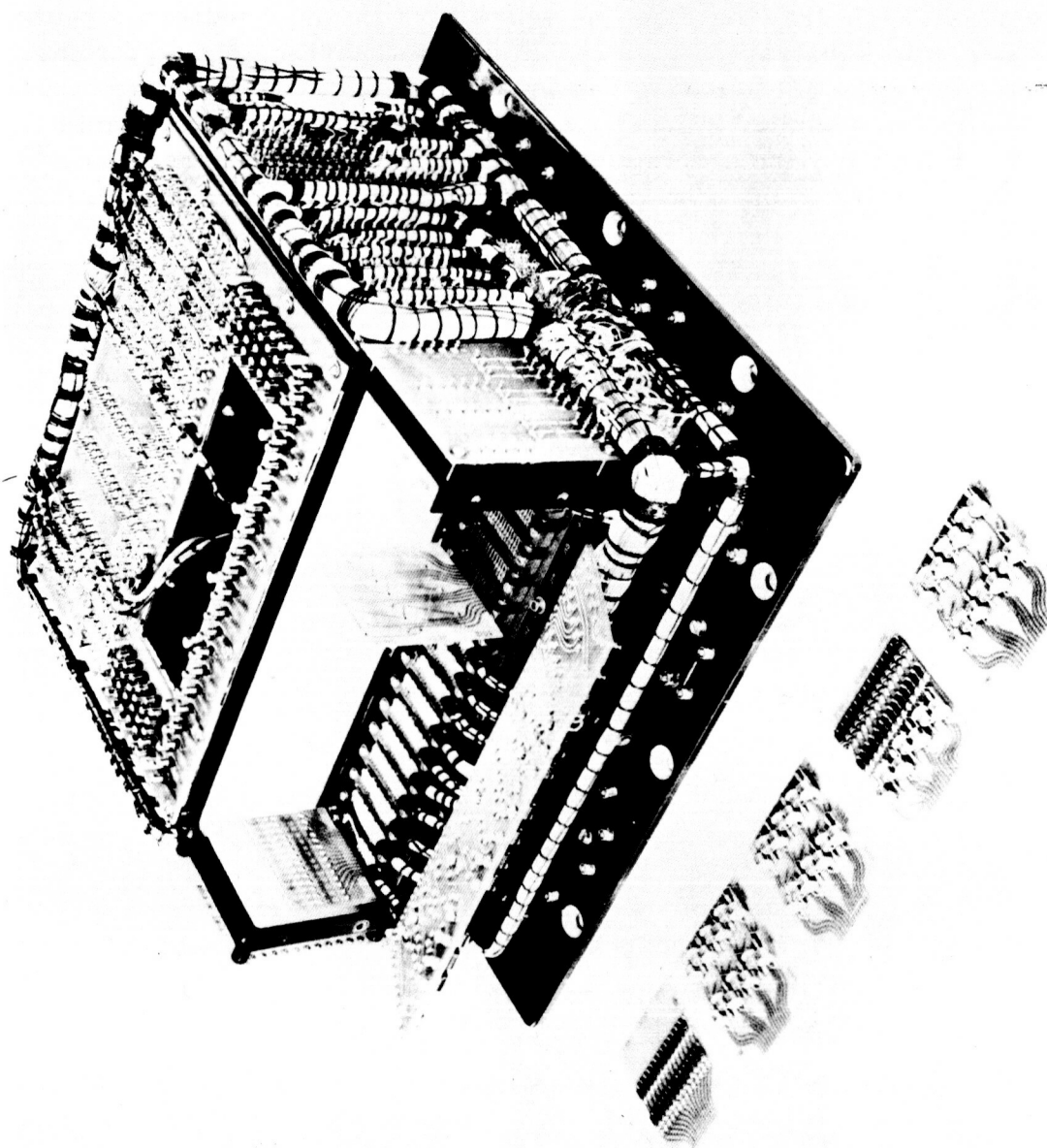


Figure 2. Signal Conditioning Box

substrate and interconnections are made by stitch bonding one-mil gold wire. They are planning to go to the ultrasonic bonded, flip-chip technique in their newly developing facility. Also, they are experimenting with a pantograph drawing machine which lays the gold pattern directly on the ceramic substrate. This technique is superior, but so far the composition of the gold coating has been troublesome. Prototype work using these new techniques is expected to get into production in mid 1967; the result will be a complete ceramic package. There is an in-house education program for designers to encourage the use of microcircuits.

d. Becon Connector

The Becon Connector, a development of the Brown Engineering Company, was originally developed for the PERSHING Missile. It is designed to screw down almost anywhere on the printed-circuit board and make connection through gold-plated pressure contacts to lands, pads, and even conductor paths. The connectors are available in several configurations including straight through (180 degrees), right angle (90 degrees), socket model (accepts printed-circuit board on edge), core model (can contain miniature circuit in hollow center), board to wire model, mounting platen for cordwood modules, and holder for microcircuit flat packs. The individual spring contacts of the Becon Connector exert 300 grams contact pressure, are rated for five amperes at 100°C temperature rise, and will not open at 30 g's of vibration. These connectors have been used on several space applications. An example of the styles is shown in Figure 3.

2. **Cubic Corporation, San Diego, California**

a. Radio Frequency Transponder

The Cubic designed satellite radio frequency transponder (600 kc) is built in modular form on a single-sided printed-circuit board having a tin-plated copper base. The top side of the board is used as a ground plane while the bottom side provides some interconnections. The metal frame is a machined shell like a sardine can. The cans are one standard size and have machined lips so they nest together. Approximately 10 of these cans are stacked together on edge in a cast aluminum module frame and held in lateral compression by four compression bolts exterior to the cans. Heat-sink plates are placed between modules wherever required and are anchored against a base plate to provide heat transfer. A shielded can equipped with a radio frequency gasket encloses the assembly.

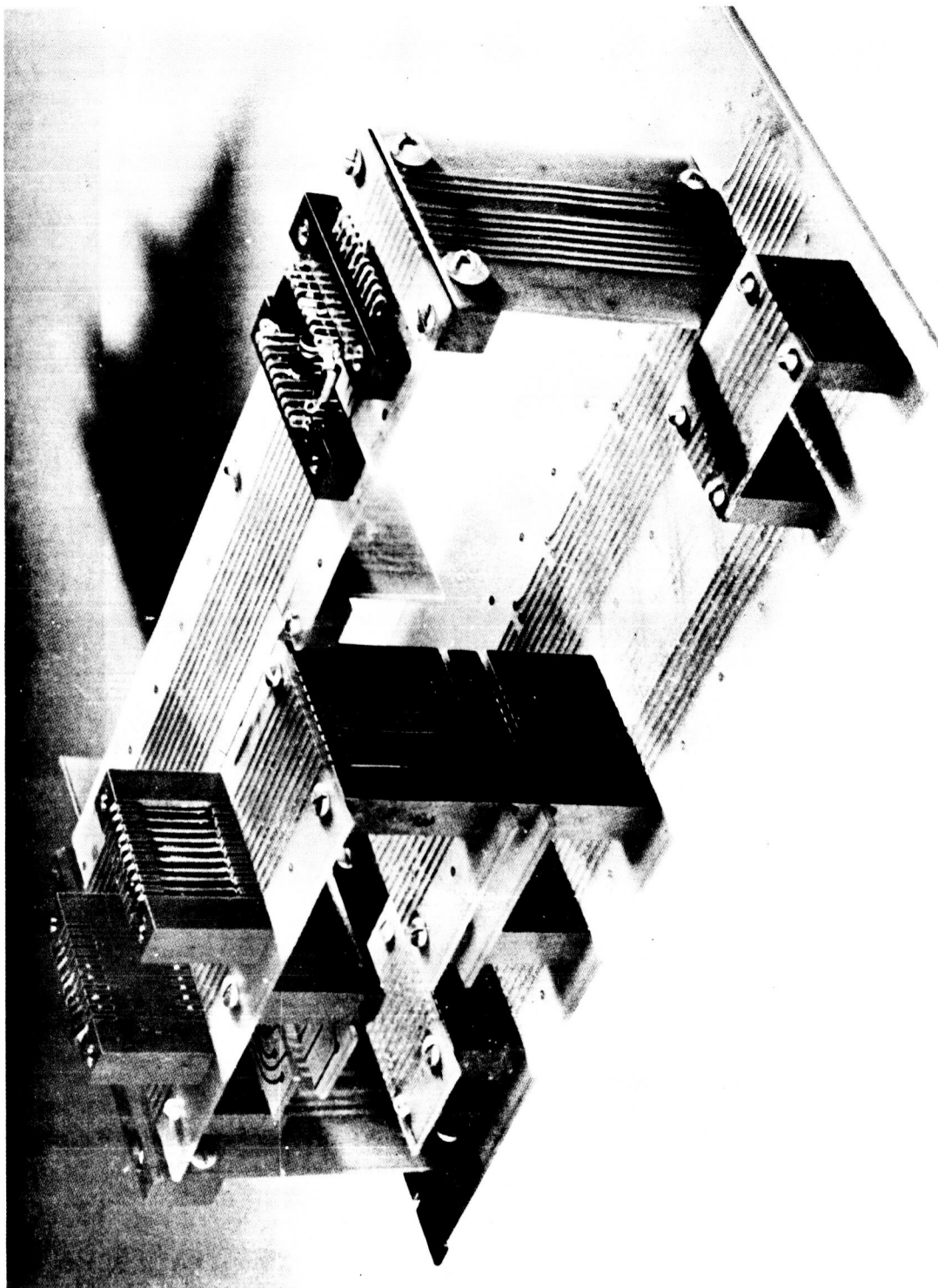


Figure 3. Module Showing Connector Applications

The connections on the bottom of the board are hand soldered in a clean room. The holes through the board are open and a "Z" wire is passed through the hole and soldered on both sides of the board. They have used some eyelets, but have had trouble and avoid them whenever possible. The module is not potted except for spot use of epoxy to anchor some of the parts. Some stake terminals are used as are some ceramic capacitor feed-through terminals. There is no printed-circuit board in the amplifier section thus making it highly repairable.

External to each module are a few terminals used for interconnections by hard wire. Radio frequency connectors come out the side of each module and are used for interconnection and connections to the outside of the package.

The package will withstand 20 g's at 3000 cycles sine wave at a random vibration of 400 to 2000 cycles per second. It is designed to withstand 200 g's shock for one-half of a millisecond. It was emphasized that all the work done at Cubic is for very low production runs.

b. Planar Assemblies

Some of the equipment designed for aircraft consists of single-sided planar boards which are wave soldered. Only discrete parts are used at the present time and they are mounted in a dense axial configuration. The boards are slid into formed metal guides to hold them in place. A hold-down plate including a silicon rubber pad is used to restrain the circuit boards in a drawer configuration approximately 10 by 15 inches. Some conformal coating is used. The equipment is air cooled. Connectors on the boards plug into the mating half of the connector located in slots on the bottom of the drawer. Hard wire is used out to the back of the unit where floating plugs are mounted. Radio frequency cover plates are used over each board as needed. The power supply section has a massive heat sink.

c. Other Components

Cubic has also made a two-watt transmitter for telemetry on the Agena system. The box container configuration is fixed, a machined aluminum case measuring  $3\frac{1}{4}$  by  $2\frac{1}{2}$  by 5 inches. Small printed-circuit boards are used. Special heat sinks have been installed to contact directly with the case.

Cubic has done some work with micrologic in TO-5 cans. A standard single-sided printed-circuit board pattern is used which consists of row paths. The TO-5 cans are plugged into the board, and the leads

are bent over on the bottom side and soldered to the pads. Each pad has two holes permitting top side hard wiring for point-to-point connections. This is to also facilitate mixing discrete parts with the integrated circuits. External connections are made via board-mounted connectors. This unit is also for low production and features ease of changing parts or wiring.

Cubic is also considering the use of flat packs and looking ahead to such things as cordwood and potting of radio frequency modules.

### **3. Douglas Aircraft Company, Santa Monica, California**

Douglas is involved in electronic packaging for ground support and missile borne electronics for the ZEUS, THOR, DELTA, and SATURN missiles, the MOL vehicle, and the OGO-F. They have also conducted a NASA-sponsored study of flat wire cabling. Their basic techniques are based on high density multilayer printed-circuit boards.

#### **a. ZEUS Components**

Three schemes are considered on this project using discrete parts. The first is a conventional four- by five-inch flat circuit board. The second is based on a  $2\frac{1}{2}$  - by  $3\frac{1}{3}$ -inch double-sided board which achieves part density by standing the discrete parts on end, i. e., normal to the board. The third approach is a cordwood assembly which may be either welded or soldered. Consideration is being given to using a double-sided printed-circuit board for this cordwood module and reflow soldering techniques.

The general assembly approach is to use a cold plate in the center of the package for the mounting of the high heat dissipating parts. Parts are then conformal coated, followed by a polyethylene foam for maximum reliability requirements. The back of the printed-circuit boards are also foamed after hard wiring for board interconnections and external connections to a connector. The entire package is designed as a symmetrical can around the cold plate to provide a center-of-gravity type mounting.

#### **b. OGO-F**

Douglas has designed and built a suitcase type ground exerciser for a portion of this system. It uses integrated circuits mounted on printed-circuit boards having plated-through holes. Connections are made by reflow solder techniques. Five of these boards are assembled together under compression.



Discrete and 10-lead round integrated-circuit packages are mounted on the 6<sup>1</sup>/<sub>2</sub>- by 11-inch double-sided printed-circuit board. A series of these boards are hard wired to the mother board. Douglas has experienced very little trouble with the plated-through holes for holes greater than 0.025 inches where the ratio of diameter to depth is no more than one to four. When the board thickness to whole diameter ratio reaches seven to one, problems can be expected.

c. SATURN Ground Support Equipment

This equipment consists of discrete components mounted on printed-circuit boards using reflow soldering. This decision is based on the quantity and cost trade off requirement. The printed-circuit boards are conformal coated. Wire-wrap connectors are used for interconnections.

d. MOL

Plans for modules on this project include using a 0.875-by 0.400-inch double-sided printed-circuit containing in-line integrated circuits. The board will contain edge mounted contacts which are nickel-rhodium plated on copper placed on 100-mil centers. Each card is conformal coated and plugs into a connector directly. The use of 100-mil spacing provides an advantage of more room for the printed circuit between each connector.

e. General Packaging Investigations

Douglas has conducted a study on printed-circuit flat cable under contract with NASA. Problems of computing bends, acceptable folds, and stacking techniques have been investigated along with methods for connecting wires to connectors. Interconnection ease and low cost systems have been a primary concern. One of the limitations has been the availability of suitable connectors. However, NASA is considering the problem further and investigating a series of connectors in which the cable can be stripped and molded into the plug. Other types of connectors are available but it appears some standardization is required in this area. Basically this type of wiring is expensive, but it appears production savings may more than offset the difference. The flat cable has superior abrasion resistance with respect to a conventional type bundle without a protective jacket. It has been noted that the mylar cable is temperature limited.

Some investigation has also been made of wire-wrap techniques. Hand wire wrapping results in an 85 percent labor saving over hand

soldering, and it is expected that automatic wire wrap would result in an even greater savings. Wire wrap also has the advantage of being easy to change, and it has fairly good resistance to acceleration. Some consideration has been given to using wire wrap on a Termi-Point system for interconnecting flat cable connectors.

Development work on multilayer printed-circuit boards has also been conducted investigating the value of 8 to 12 layer boards. However, there are problems with the reliability of plated-through holes and the usual problems of replacement and changes in design. Use of multilayer boards becomes economical only when large quantities are involved. For most cases, it appears a six-layer board would be sufficient. Future work and development will consider automated placement of flat packs on printed-circuit boards and further investigation of reflow solder, resistance solder, and welding techniques.

#### **4. General Dynamics, Convair Division, San Diego, California**

General Dynamics makes an electronic module containing flat packs which uses a one-mil mylar base as an interconnect panel. It is double sided and has plated-through pads. The ability to etch away the mylar and provide the plated-through pads, thus permitting opposing electrode welding is General Dynamics' primary advantage in this technique. Each of the mylar films has several spare weld pads to permit test welding to verify weld schedules each time the part is changed. (These welds are checked by quality control people with pull tests.) The bottom part of the pad is recessed thus permitting the use of a square electrode and providing a locating technique for accurate welding. (This technique is discussed in a paper presented at NEPCON, 1965, entitled "A Planar Approach to Resistance Opposed Electrode Welding.") The circuit on the mylar is one ounce copper plated with three mils of nickel. The parts are placed on one side of the mylar base. The design is such that it is easy to include discrete parts with the flat pack. The assembly is welded including such materials as dument, nickel, kovar, and oxygen-free copper. For the integrated circuits, a double size pad is used with a double welding technique. For the other parts, the double size pad is used in conjunction with long leads thus permitting them to clip out a part and weld in another one using the remainder of the pad. Pins are welded to the pad to bring signals out of the module and are interconnected with point to point thus avoiding connectors as much as possible.

The module is put in a tape-milled aluminum frame and conformal coated with polyurethane. When all of the modules have been put in the "black box" and bolted to a deck they are foamed with rigid polyurethane. Although the rigid foaming limits maintenance, the polyurethane does not support combustion and it has dimensional stability and little post curing growth. The modules are in various sizes such as two by three inches or three by five inches. The flat pack modules are in modules  $2\frac{1}{2}$  by  $2\frac{1}{2}$  inches. It was emphasized that this technique is advantageous for small quantity prototype production. However, General Dynamics would use multilayer mother boards with this technique if they were manufacturing a large quantity.

**5. Honeywell, Incorporated, Aeronautical Division,  
St. Petersburg, Florida**

Two general areas of electronic packaging were discussed at Honeywell; the packaging of circuits and the packaging of systems. Personnel of the Marketing Group and the Integrated Circuit Producing Group discussed Honeywell's activities in the large-scale integrated-circuit field.

**a. Large-Scale Integrated Circuits**

Honeywell is shunning the hybrid approach to large-scale integrated circuitry (i. e., multichip and mother board assembly) and going the route of the large monolithic chip which can contain many circuits and even subsystems. The ultimate goal is a complete system on a single chip which Honeywell feels is possible.

Currently they are producing for in-house use a series of shift registers. Principal among these are a 10-bit serial shift register mounted in a standard 14-lead flat pack, and a 10-bit parallel input-output shift register that is the equivalent of 23 integrated-circuit flip flops. The circuit mounts in a 26-pin flat package. Honeywell is also producing a digital word translator that has a "read only" capability of 64 words at 24 bits per word. This device, essentially a diode matrix on a 0.22- by 0.29-inch chip, has its memory fixed during production by a technique of burning out unwanted diodes from the matrix with a high-current pulse. The resulting truth table requires only 39 pins out but is presently packaged in a 46-pin ceramic flat pack approximately three-fourths of an inch square. A conductor pattern, etched from a gold layer deposited on the ceramic base of the package, serves to interconnect the chip and the flat pack leads. Presently, flying-gold leads connect the chip pads to the conductor paths and the conductor

paths to the outside package leads. They are working on a technique to eliminate the second set of flying leads by directly connecting the conductor paths to the flat-pack leads.

b. TO Series Enclosures

Honeywell is seriously looking at large versions of the TO series of semiconductor cans that would accommodate the large-scale integrated circuits. Described was a  $1\frac{3}{4}$ -by  $1\frac{3}{8}$ -inch version having 55 pins out on 80-mil centers. Their interest in this type of enclosure stems from the following points:

- 1) Proven hermetic can seal (welded metal/metal)
- 2) Proven hermetic lead seal (glass/metal)
- 3) High thermal conductivity
- 4) Auto assembly in plated-through holes
- 5) Wave solder assembly
- 6) Accommodate a whole monolithic wafer circuit.

They have considered a staggered pin arrangement for this type of package to reduce total size, but are unfavorable toward it since it does not lend itself to good adaption in the standard printed-circuit board lead configurations. Briefly mentioned were other sizes and shapes (rectangular) of this enlarged TO series can, which is being studied.

c. ALERT Digital Computer

The ALERT Digital Computer for the X-15 aircraft is a very rugged unit which uses planar mounting of flat-pack integrated circuits on multilayer daughter boards interconnected by a multilayer mother board. Presently, the flat packs are attached by parallel-gap welding individual leads. Honeywell feels welding is inherently more reliable, but that much thought has to be given to board design and standardized weld-pad configurations if consistently good welds are to be made. Soldering, while less reliable at high temperature (reduction to 20 percent of room-temperature mechanical strength at 220°C), has looser control parameters and accordingly is being seriously investigated. They are looking into soldering individual leads, 14 leads, and even 20 leads at a time.

The daughter printed-circuit boards, which mount flat packs on both sides, are 30-layer plated-through hole boards; actually these boards are two similar 15-layer boards as follows:

- 1) Weld pattern
- 2) Ground plane
- 3) Voltage plane
- 4) Ground plane
- 5) Clock plane
- 6) Ground plane
- 7) to 15) Logic planes.

The insulation thickness between layers six and seven is made as large as possible to isolate the logic signals from the ground plane. Further, the logic patterns on each layer are localized to minimize cross talk: alternate logic layers are routed normal to each other to minimize capacitance effects. Each board is equipped with a slave clock circuit that is driven by a master clock circuit in the computer.

The daughter boards, as described, are joined to a 21-layer mother board either by connector assemblies or by flat flex-cable links. A system of laminated bus bars is used to route voltages and grounds in the computer. Finally, flat flex-cable wiring (and sometimes cabled hard wire runs) is used to connect the mother board to the input/output connectors. These cable links are potted into the back side of the connectors.

In final assembly, three daughter boards are bolted to either side of a central structural web with a system of bonded-on spacers maintaining the distance between the daughter boards; eight bolts are used. Thus assembled, each board shows a low inherent resonance, and cushioning or compressive pads are not needed. A polyurethane conformal coating is air sprayed on the boards after final checkout; the housing is not hermetically sealed.

Testing of the unmounted multilayer boards has proven to be a major time factor in the construction of this computer. Both the daughter and mother boards are 100 percent tested as received and again after an elevated temperature exposure of two days. The incoming integrated circuits are also 100 percent tested throughout a temperature range of  $-55^{\circ}$  through  $+100^{\circ}\text{C}$ . The daughter boards are again tested when completed and the final assembly is then tested at elevated temperature before conformal coating.

## 6. Hughes Aircraft Company, Culver City, California

A very real difference exists among the overall electronics requirements for missile application, satellite operation, and manned space flight use. The Hughes organization has approached the delineation of these varying needs by the establishment of a set of physical design standards for programs in their research and aerospace groups. Evaluation of their proposed electronic designs uses a system of weighting factors for such pertinent considerations as weight, volume, reliability, thermal dynamics, manufacturing ease and cost, maintenance, procurement, interconnection technique, and time schedule. There are latent feelings within Hughes that the various companies involved in aerospace production should interplay more extensively for the benefit of the United States Government. An important yield of this action would be a substantial decrease in interface and mounting problems between the subsystem packages from different sources for a given aerospace system.

### a. State-of-the-Art Studies

Hughes techniques for assembling electronic packages are reported to range from the very earliest to the very latest. Their developments in the flip bump chip approach to the next generation of electronic circuitry have been reported. Currently, they are evaluating the various schemes thus far developed to determine whether the bump chip, the bump substrate, or some other method will be optimum: the bump chip appears to be more repairable at this point. They are seriously looking into large scale integrated circuit designs for the packaging of digital circuits but intend to stay with the flip chip approach to linear circuitry. The thick-film substrate is favored over thin film for the near future: thin films are generally more expensive and the advantages of geographic conservation and tight-tolerance capability are not so important to Hughes.

### b. Current Practices

In current design practices, Hughes does not favor the multilayer printed-circuit boards because of the expense, questionable reliability, and inflexibility to design change. They make use of multilayer boards up to 10 layers thick where required, but prefer to design around them. Multilayer boards do have an advantage over hard-wire harness after moderate production quantities but at the risk of lower reliability. Both Termi-Point and wire-wrap are favored for hard-wire connections and are used extensively in their designs. For some units, in-house manufactured printed contour cabling is used. Daughter boards are attached to mother boards directly and secured by wave soldering.

Connectors at this level are considered to be unreliable and contribute excessively to the total weight and volume of the package.

c. HCM 205 Computer Package

Hughes packaging engineers approach new designs with thermal dynamics being one of their prime considerations, and they use computer programs to assist this phase of planning. An example is a heat exchanger designed as a mount for electronics in the HCM 205 computer. Intended for airborne use, this design is adaptable to aerospace application by conversion in the cooling system. The computer circuit is organized on the horizontal or bit approach rather than the vertical or function approach, as is more common. This circuit concept contributed to the use of right angle technology in the mechanical design.

The basic building block of the HCM 205 computer is a close-tolerance tape-milled, 60-61 aluminum cell frame, 3.5 by 6.5 by 0.7 inches in size. In the Arithmetic Module, 20 cell slots oriented in the 3.5-inch direction and located side by side along the 6.5-inch direction are milled completely through the block thickness. The daughter printed-circuit cards are contained within these cells, two per cell facing each other and backed against the aluminum web separating the cells. One side of the aluminum frame is relieved to accept the mother printed-circuit card which runs nearly the length of the frame. To one end of the cell frame is mounted a standard Malco 136-pin connector which makes connection with the conductor pattern on the mother card through stagger-bent right-angle pins. A series of small holes is milled through the block along both 6.5-inch sides, to conduct the cooling medium. A given number of aluminum cell frames, with appropriate end plates, are stacked up and bolted together to form the package structure, complete with forced cooling channels from end to end.

Both the mother and daughter cards are of plated-through hole, two-sided, copper-clad laminate construction with an overall plating of solder. The daughter cards are approximately 0.7 inch wide, 3 inches long, and 15 mils thick and will accommodate eight 14-lead flat packs: mother cards are 25 mils thick. Along the lower edge of the daughter card are extended fingers on 100-mil centers which insert into the mother card and are wave solder secured. As Hughes views this right-angle technology, they are obtaining the interconnection capability of a six-layer board, while circumventing the objections to multilayer board. Also, within the total design concept, the density which they achieve is considered good, being in the order of 12 to 12.5 flat packs per cubic inch at the module level and 11 to 11.5 flat packs per cubic inch at the system level.

The daughter cards stand freely next to the hard anodized surface of the aluminum web. Thermal lag through this small air space between the board and web has been calculated to be 4°F. In the airborne computer, where air is used as the cooling medium, a 20-degree temperature differential has been measured between the flat-pack case and the air supply inlet. The mass of the individual daughter cards is small; no problems have been encountered at vibration levels up to 20 g's. For high vibration requirements, a silicon-rubber tank-tread-shaped blanket which lays across the top of the module and wedges the individual daughter boards against their respective webs, is envisioned.

For the memory units of the HCM 205 computer, the outside dimensions of the aluminum module frame are identical to the Arithmetic Module, but the thickness varies according to need. The memory circuit construction is a hybrid of integrated circuits and discrete components. All semiconductors are either of the hermetically-sealed flat-glass-package type or are packaged in standard 14-lead flat packs in dual and quadruple transistor combinations. Discrete capacitors, of case size A, are used with the leads flattened for easier attachment. Thin-film resistor substrates are used extensively in lieu of discrete resistors. In practice the transistors in flat packages are parallel-gap soldered to the thin-film resistor substrates and potted in epoxy for protection. Parallel-gap soldering of the flat packs and discrete components is preferred because of inspection ease and repairability. The package often contains two resistance substrates because of a wide spread in either resistance or power values; e. g., a 60-ohm resistor is not feasible on a substrate designed for 1000 to 10,000 ohm resistors nor is a 2.5-watt resistor compatible with low wattage resistors on a single substrate. A resistance tolerance of one percent is maximum for the high power resistors with the more critical elements maintained to 0.1 percent. Of the eight types of thin-film assemblies built for this computer, one has a maximum heat dissipation of 2.7 watts in a 0.25- by 0.5-inch package at a 20°C temperature rise. The thermal resistance of an assembled board is 1°C per watt.

High-insertion-force connectors (six to eight ounces per pin) are used in the computer base. These are interconnected by hard wiring attached by wire wrapping to the rear of the connector pins. In assembly the aluminum module frames have no gasket between them for air cooled applications at less than 200,000 feet altitude; a maximum of five percent cooling air leakage is realized. For higher temperature environments where liquid cooling is desirable, a gasket can be used between



the module frames for absolute sealing. Satellite application would see the modules spread apart, and a cold plate inserted between every module pair. Also, each module would be vacuum impregnated with low-vapor-pressure silicon wax for heat transfer from the daughter boards to the aluminum web.

## **7. Jet Propulsion Laboratory, Pasadena, California**

The Advanced Technology Group at Jet Propulsion Laboratory has the function of originating new ideas and new approaches to spacecraft electronics and pacing the state of the art. The recent activities include the integrated-circuit stick module with a hard-wire or etched-conductor interconnect scheme, the wirecon module, high impact packaging, measurements of internal compressive forces within potted modules, interconnection technique studies, etc. Work with thick and thin-film substrates, flip chip, etc., is also being undertaken. Of course, much of their concern is related to low production quantities and the need for frequent design changes.

### **a. Stick Module**

In the last couple of years Jet Propulsion Laboratory has investigated the multilayer board, laminated comb, magnet wire stick module, and molded interconnect board. All of these schemes have suitable application depending on the particular product. Of these, the technique which has attracted the most recent attention has been the magnet wire stick module.<sup>1, 2</sup>

The stick module is a molded mounting frame which holds 15 integrated circuits (Figure 4). The integrated circuits or discrete parts with suitable lead adaptors are welded or reflow soldered to contacts. The contacts are brought out as terminals on the back side of the stick which is a thermal setting plastic (EPIALL) (Figure 5). Interconnecting

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<sup>1</sup>Leonard Katzen, COMPLEX INTERCONNECTION OF FLAT PACKS WITHOUT MULTILAYER BOARDS, Electronic Packaging and Production, Vol. 5, No. 12, December, 1965, pp. 60-62.

<sup>2</sup> Jet Propulsion Laboratory, Pasadena, California, PACKAGING FLAT PACKS FOR SPACE APPLICATION by Leonard Katzen.

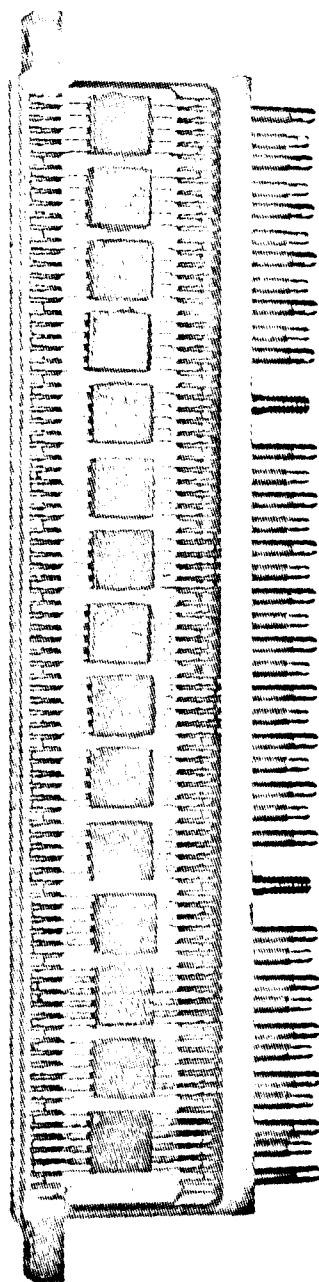


Figure 4. Component Side of Module

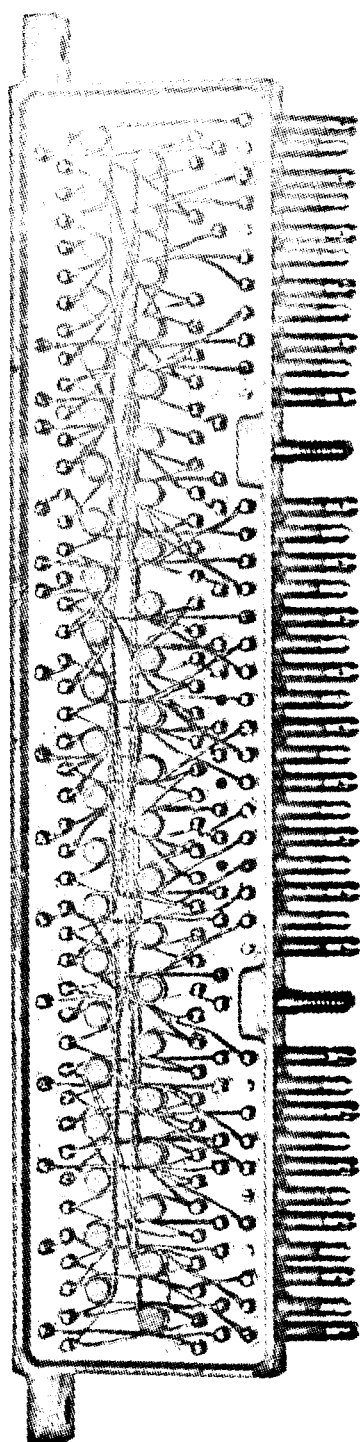


Figure 5. Wiring Side of Module

wiring is done by hand with the aid of a pencil-like tool which feeds the Formvar-coated magnet wire through the tip under constant tension. Edge connectors are molded into the stick carrier which plugs directly into the mother boards. Since the wiring complexity is handled on the stick, the mother board wiring is straight through and therefore quite simple. It is believed that the volumetric disadvantage of this system is outweighed by its flexibility and reliability for a spacecraft packaging application. Techniques have also been developed for soldering through the insulation of the magnet wire without the need for stripping.

Another approach is building a comb-type wiring pattern somewhat similar to the Motorola micro-harness. Jet Propulsion Laboratory's laminated comb technique is intended for limited production where inexpensive reproducibility is required. The laminated comb technique is used by several companies in various forms. The layout can be predetermined as an art work layout or a punch tape control, the necessary patterns formed, and layers build up. When correctly done there will be one comb finger extending for each integrated-circuit flat pack lead, thus simplifying the weld schedules and connection techniques required (Figure 6). The approach has many of the advantages of the multilayer printed-circuit board plus the advantages of several simple visual inspections. (Other manufacturers have made complete combs and removed the fingers which were not needed.) The approach does have limitations as to the number of flat packs which can be conveniently attached, and there is the problem of wiring from the lead terminals to the next assembly. However, the input/output leads from the laminated comb can be arranged to have greater spacing than from the standard flat pack thus alleviating to a certain extent the external connection problem.

b. Wirecon Module

This is a cordwood-type module developed for low quantity usage of discrete parts. It eliminates the need for a multilayer printed-circuit board and thereby makes it possible to inspect all joints. It differs from cordwood in that all of the connecting beam leads run in the same direction feeding through a plastic header to serve as pins on a plug or as wiring terminals. The necessary crossover interconnects are included in the basic module. The entire module is potted in epoxy. It is considered suitable for integrated circuits because of the relatively low density. Normally 24 to 28 pins are accommodated for each module.

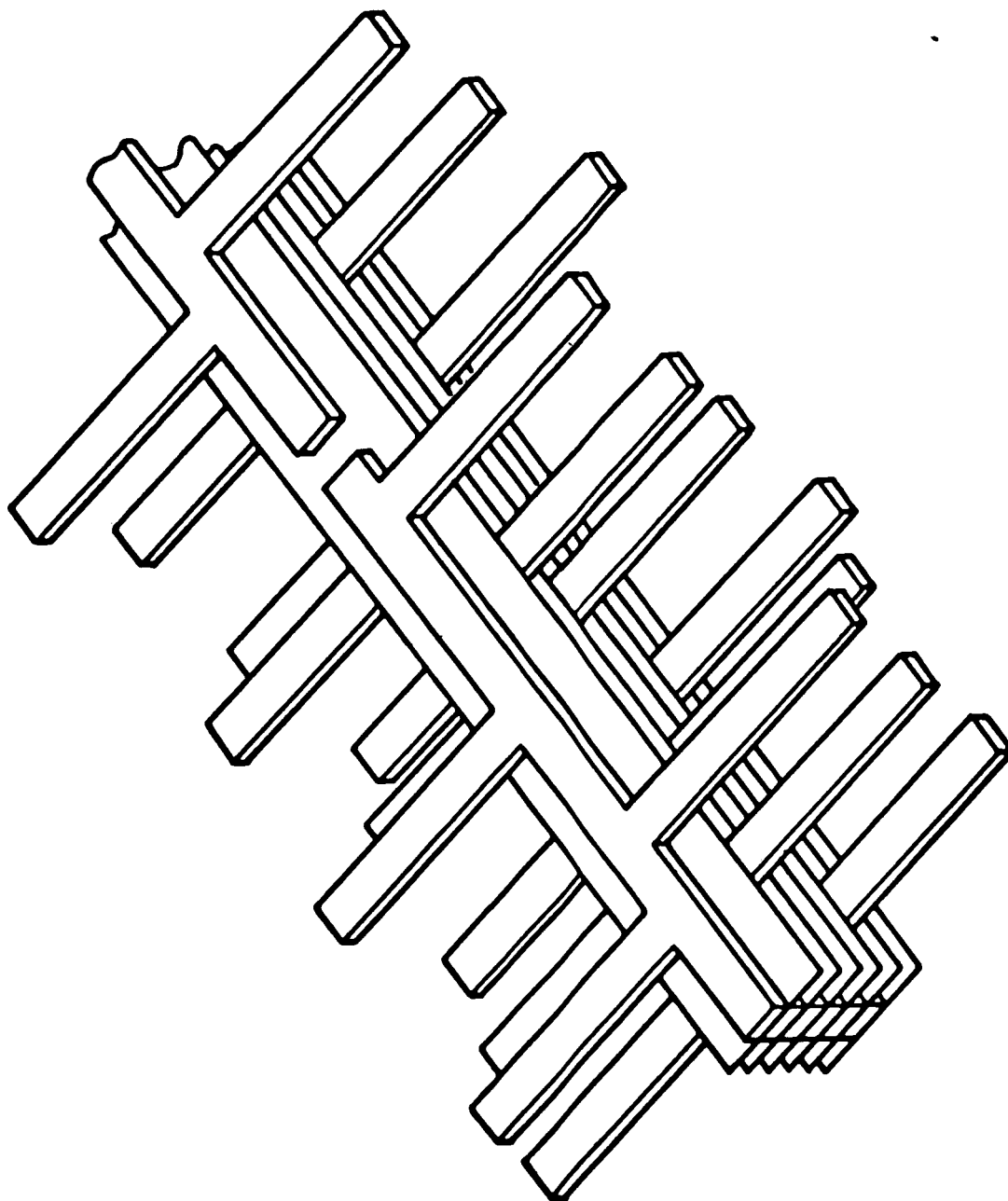


Figure 6. Superimposed Segmented Trunks of Comb Pattern

c. Molded Interconnect Board

The development of this technique was initially started by Electronics Engineering Company. It consists of machining a waffle-like pattern on a sheet of stainless steel, nickel, or other metals (Figure 7). Magnet wire is then routed from the pads thus created and welded. The entire block is then potted on the wire side of the plate. The plate is then machined away from the plastic until only pads are left embedded in the plastic. Thus there remains a plastic block with interconnected pads (Figure 8). The parts are then welded or reflow soldered to the pads. Etched fingers on the board for external connections can be made in the same manner as the pads. All of the pads and etched fingers can be the full thickness of the board if so desired. It is also relatively easy to include heat sinks or a mounting frame in the molded assembly as an integral part of the interconnect board. This approach is quite interesting for low quantity production and cheaper than a multilayer board. However, there is a crossover between the two techniques as production quantities go up.

d. Mariner C

One of the packaging objectives investigated for the Mariner C was to eliminate conventional wiring. This was done by the development of a two-sided printed-circuit board which is approximately 25 inches in diameter (octagon shape, approximately 10 inches on the side). All plated-through holes are redundant to avoid filling them with solder. This makes a weight difference of one pound. The substitution of this printed-circuit board for conventional wiring reduced the weight from 10 to  $2\frac{3}{4}$  pounds. Another feature of this packaging was the means of bringing the wires from the connector board to the right angle connectors. This was done in such a manner as to permit visual inspection of every joint. It is also possible to replace connectors by cutting out the connecting wires and replacing them.

One of the electrical difficulties was 2400-Hertz square-wave signals leaking into other circuits. Isolation was established by starting in the center of the octagon in a circular pattern with the most severe noise source (2400 Hertz) followed by the 400-Hertz signals, etc. In the final design, 95 percent of the circuits had less noise than the cable version, and the remaining five percent were still acceptable. Some ground plane lines and some transposing of power lines (equivalent to twisting leads) were also used. Power was plugged in one end of the board and the signals in the other end.

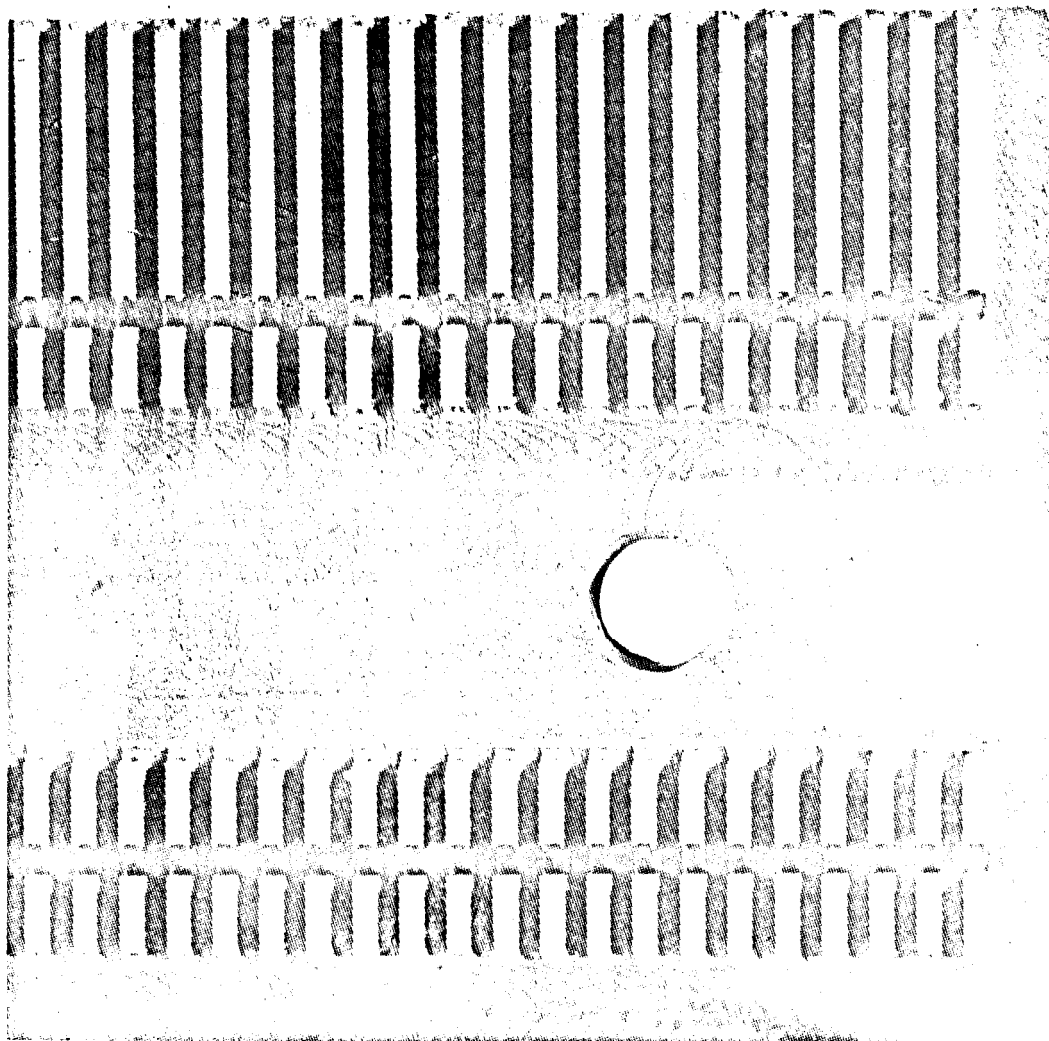


Figure 7. Close Up of Machined Plate

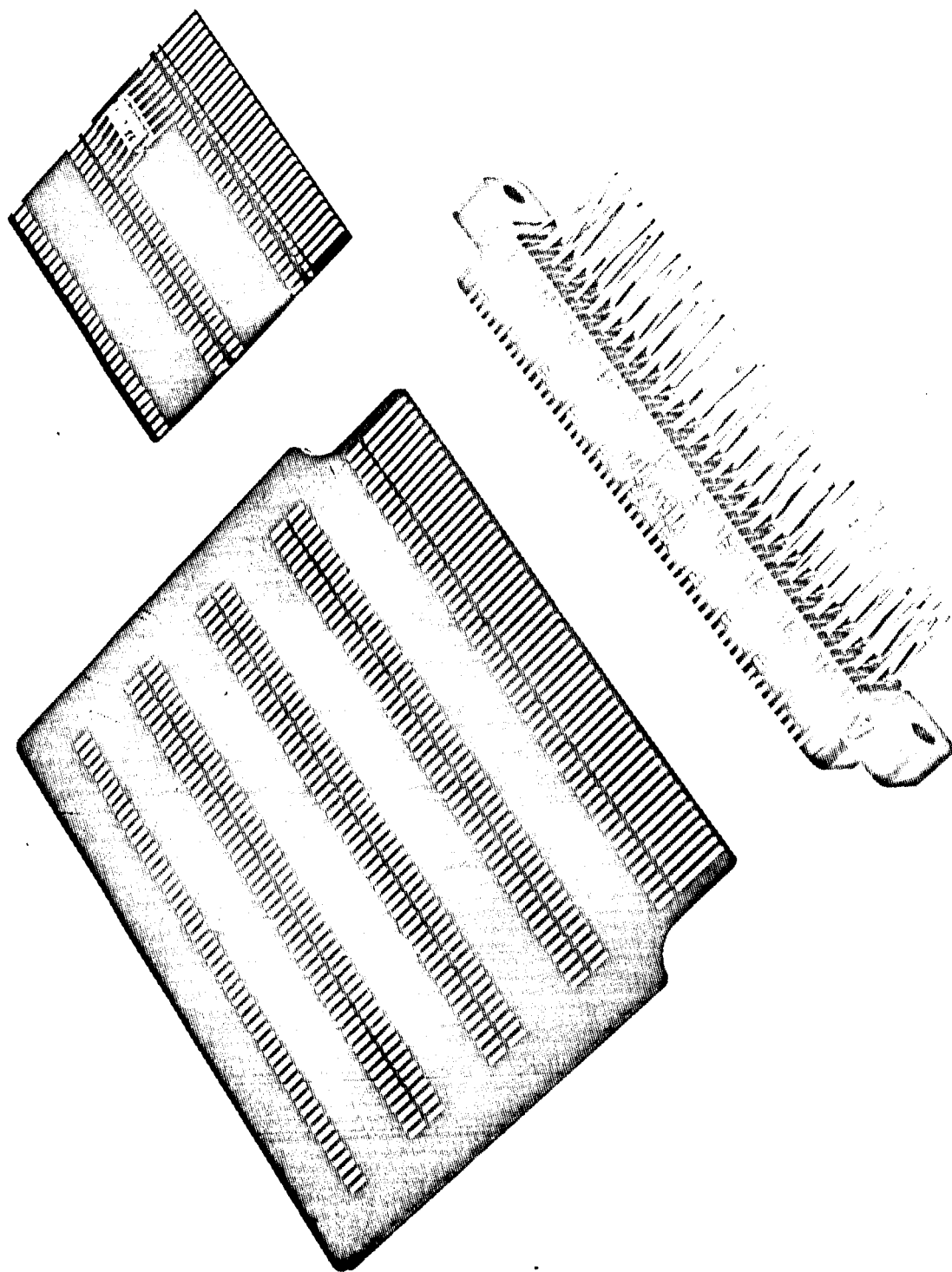


Figure 8. Molded, Etched, and Ground Plate



e. Other Investigations

The Advanced Technology Group is also investigating the pressure exerted on parts in the potted module. Pressures greater than 3000 pounds per square inch have been observed at  $-40^{\circ}\text{C}$  in unfilled Stycast 1090. The use of an RTV coating on the components together with a microballoon filler in the Stycast 1090 reduced pressures to 300 to 400 pounds per square inch at  $-40^{\circ}\text{C}$ . Instrumentation development and further investigation are continuing.

Another area of interest is the problems imposed by sterilization at  $300^{\circ}\text{F}$ . One study involving a fixed transistor flip flop on a 28-pin module indicated that it could tolerate  $-100^{\circ}$  to  $300^{\circ}\text{F}$  without degradation. This experiment was done by bringing out every node on the circuit to permit measurements on each part of the circuit as well as to enable its operation as a total flip flop. Another problem is that of high voltage stresses. It has been reported that there has been many accidental failures of equipment in the 65,000- to 310,000-foot range resulting in corona and damage to other parts. Problems include voids in potting around transformers which permit corona, and foam compounds emitting gas in critical regions. The objective is to meet a five-year spacecraft life at 10,000 volts direct current. To this end Jet Propulsion Laboratory is constructing a five-story chamber that is to be capable of a pressure of  $10^{-7}$  millimeters of Hg at  $-240^{\circ}\text{F}$ .

Other studies under way include development of weld and solder techniques and schedules for various types of metals and insulated wire.

8. **Ling-Temco-Vought Electrosystems, Incorporated,  
Garland, Texas**

Ling-Temco-Vought (LTV) Electrosystems, Incorporated, designs and constructs electronic devices from the level of subsystems to total systems for aircraft, missile, and manned spacecraft applications. Both analog systems and low frequency (20 kHz) digital systems are represented. LTV prefers the planar printed-circuit board construction with flow soldering attachment of discrete components. However, they have not restricted their designs to this premise, having used many and varied techniques as required by their applications.

a. Planar Modules

A number of innovations has been devised in the use of printed-circuit boards to achieve some degree of volumetric efficiency.

One of these is an assembly of facing planar boards which is interconnected at the top edge by flexible flat cable links. The boards are wired laying flat (side by side) then folded and soldered into a mother board or to a module header. Board sizes range from three-fourths by one inch up to one by two inches. In the module application, two and often three boards are used, either side by side or for three boards in an inverted channel configuration. Such modules are potted using a length of rectangular, opaque, fiberglass tubing as a former which butts against the header and is filled with potting compound to the top: the potting material forms the top of the module. Such modules are considered to be throw away items.

Another design, using planar printed-circuit boards, is presently in the latter stages of development. This is an open module of three parallel boards, approximately four by five inches in size and spaced  $\frac{1}{16}$  inch apart. The  $\frac{1}{16}$ -inch-thick center panel which contains the basic interconnect scheme extends beyond the two outer boards along the sides and at the bottom: the side extensions slip into guides in the package and the bottom extension serves as a printed-circuit plug. Both discrete components and integrated-circuit flat packs can be mounted on the outside of the  $\frac{1}{32}$ -inch outer boards. The three boards are interconnected by short lengths of wire set in notches around the sides and top of the boards and soldered in place. In the developmental system, 30 of these modules are mounted in a cast aluminum housing having a screwdown lid with a radio frequency gasket. Spring-loaded card slots are used to maintain the card modules laterally and a plastic handle in the top of each board exerts the necessary downward pressure with the lid in place to contain the module vertically. The unit, having only a five g vibration requirement, has been successfully tested to 10 g's. Conventional hard wiring provides the interconnections between Hughes' 86-pin print-pin-terminal module connectors and the input/output connectors.

#### b. Welded Modules

The designers at LTV do not favor multilayer printed-circuit boards and cordwood modules and have not used them except when forced to do so by the design requirements. The soldered cordwood module is rejected due to past experience with internal joints becoming unsoldered during the soldering of external module leads. As an alternate to cordwood construction, per se, they have used the technique of welding discrete components in an open planar configuration and assembling three such welded layers side by side (vertically) with the interconnects between the layers being made across the top edges. Tooling cards, having printed wiring patterns, are used to hold the components of each layer during the welding operation. All welds are

of the cross-wire type performed by opposed-electrode welding. Thin-end platens hold the layers in correct relationship during interconnection and potting.

c. Weld Testing Procedures<sup>3</sup>

LTV Electrosystem's interest in and extensive use of cross-wire welds in their construction work has resulted in a superior method (flexure testing) for testing the strength of such welds. Flexure testing is capable of detecting the ductility of the wires in the weld area as well as the tensile strength of the welded joint; the more conventional pull test is used to determine tensile strain only. A prototype testing machine was developed in conjunction with this new test method. A conventional cross-wire test-weld configuration is used, with one of the wires being held firmly in place while the other is moved back and forth (planarly) 45 degrees in each direction with respect to the fixed wire. Failure criteria is the number of cycles to failure. The results when plotted yield a distinctive peak in the test curve as against the usual flat curve resulting from conventional pull strength tests.

d. Integrated Circuit Modules

LTV prefers the flat pack to the TO-5 can for the following reasons:

- 1) TO-5 cans generally require multilayer boards if compact designs are to be realized
- 2) Flat packs can more readily be parallel-gap soldered to the board
- 3) Both sides of the board can be utilized for flat pack mounting.

Several jobs in the past have required the parallel-gap welding of flat pack leads to both nickel- and kovar-clad boards: in general, it was found to be expensive and hard to control.

e. Interconnections

Both welding and soldering have been used by LTV in their designs, sometimes in the same unit. One of the principal

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<sup>3</sup>WELD FLEXURE TESTING, SUCCESSOR TO METALLURGICAL ANALYSIS by John Saul, SAE-WEPA Conference, New York, New York, October 27-28, 1964.

considerations in the selection of an interconnection method is field repair. This company feels that soldering is more tractable in this regard and more controllable at the process level. Their preference is tempered by the environmental limitations on solder bonds, e. g. , the degradation of solder strength in high temperature applications. Gold plating of boards and leads was found to be unsatisfactory and the preference is for flow-solder tinning of the boards and pretinned component leads. A rather interesting adjunct to the general subject is the use of nickel ribbon for interfacial wiring which allows soldering a joint before an adjacent joint unsolders due to the thermal resistance of the nickel.

Connectors, internal to the black box, are disliked. The preference is the direct soldering of modules and daughter boards to the mother boards and the interconnection of boards and input/output connectors with hard wiring. Cable loops are used to permit the withdrawal of a board from a package for inspection and servicing. These cable loops are laced and fastened to the board to relieve strain on the soldered points. Some boards make use of a crimp-type terminal which is crimped once to the insulation of the wire and again to the strands of the wire; this terminal is then soldered into a plated-through hole in the board. One system, using the described termination technique, has a central wiring trough which served 20 boards via branch cables that were routed down channels in the case side (adjacent to the board slots) to the bottom of the boards. The boards rested on a rubber compression pad on the bottom of the case and were pressured into it by a ladder-type sub lid at the top. Printed cabling is currently in the pre-production phase for new systems.

#### f. Potting Compounds

LTV has standardized on three materials for their module potting: Scotchcast 241, urethane foam of 18-pound density, and boron-nitride-filled epoxy for high heat conduction. They use conformal coatings on their printed-circuit board assemblies primarily to protect against intermediate handling since most such assemblies are put into hermetically sealed packages. Spot potting has been used effectively to eliminate the breakage of otherwise unsupported component leads in vibration environments. This is essentially a technique of daubing small amounts of potting material in strategic places. An allied item to the general category of potting is the use of a cast aluminum frame within a potted 16-watt servo amplifier module to which were mounted the power transistors. This module, which used subassemblies of the welded planar layers of discrete components previously described, was potted as an entity.

## 9. Major West Coast Manufacturer

### a. Cordwood Module

Past packaging activities at this company were concentrated on a cordwood type of module using a cross wire grid matrix. It was believed that the welding of a point contact-cross wire could be achieved more reliably than welding a round wire to a ribbon connector. Layers of 17- or 25-mil round nickel wire were built up interspersed with mylar film. Unneeded grids were cut out and the entire module (approximately  $1\frac{3}{16}$  by  $2\frac{3}{4}$  by  $\frac{5}{16}$  inches) was encapsulated in Stycast 1090. This technique was used for building up four layers of interconnects similar in function to a printed-circuit board. Pull strengths achieved were from 18 to 24 pounds.

Appropriate grid wires were extended beyond the potting to serve as pins for connecting to the mother board. The leads from the circuitry in the 8- by 8-inch epoxy fiber glass mother board are turned out at right angles at appropriate positions throughout the boards and holes drilled adjacent to the leads so that the modules could be plugged in. The module pins are then adjacent to the right angle mother board circuitry, and wire wrap is used for the connection. This permits a high density assembly with field replaceable modules. The mother boards are then bolted to the basic chassis. External connections to the mother board are from a terminal strip to an external harness in conventional wiring outside the complete package.

Some problems were encountered with bending the tab from the mother board to a right angle position, so an alternate approach was developed consisting of punching somewhat larger holes through the mother board and electrochemically forming an extended eyelet through the board. The eyelet would then make contact with the desired circuitry in the board, and the lead from the module would be passed through the eyelet. An extended portion of the eyelet with the module pin inside could be welded with opposed electrode techniques.

### b. Future Plans

Through a reorganization of assignments in the establishment of an electronic packaging department, this company is planning a major step forward in packaging techniques by skipping the current planar assemblies and going directly, at least, to hybrid chip packaging. The planned approach is to use masks to selectively deposit thin-film interconnecting circuits and thin-film passive parts. The substrate will also mount some discrete active parts. This company believes that the thin film approach is more reliable than etched circuits. The entire

package may be in the form of a 32-lead flat pack with sizes varying from one-fourth by one-half inch to one by one inch. Etched circuits will be avoided. The base will be an aluminum-oxide ceramic material of the size to accommodate 10 or more integrated circuit type chips.

c. Potting Studies

A particular problem of concern to this company is the lack of uniform density achieved with certain types of potting techniques. For example, Stycast 1090 with spherical filler cured under inadequately controlled conditions can result in density variations from 0.85 to 1.5 resulting in significantly different exothermic stresses which can crack a glass package. If the module to be potted is in a nonuniform environment resulting in part of the compound becoming too hot, the potting compound will be extremely viscous and some spheres will float while the broken ones sink to the bottom leaving the center with none of the filler. This results in the density differences mentioned. These problems can result from improperly designed molds or a poor oven.

**10. Motorola Aerospace Corporation, Phoenix, Arizona**

Several projects were discussed such as Mariner, Arod, and APOLLO. Electronic packaging personnel have been and are engaged in several interesting developments for system and subsystem electronics. In addition, there is a central mechanical engineering division that supports the packaging engineer on basic problems such as thermal dynamics, interconnections, encapsulation, and case structural designs.

a. Packaging for Spacecraft Applications

Requirements for such environments are, of course, high reliability, high component density and low weight, complex circuit interconnections, and severe environmental stress. The approach consisted of using a cordwood like module with welded ribbon interconnects and arranging the modules on opposing printed-circuit boards such that the modules from the opposite boards will interleave as the printed-circuit boards are closed as leaves in a book. The board wiring goes out to one edge. These developments are basically NASA-sponsored activity through the Jet Propulsion Laboratory (Figure 9).

The modules or building blocks used are those such as are shown in Figures 10, 11, and 12. Each one is an electrical entity and can be tested before assembly to the mother board. Uniform pin spacings were selected and module sizes were maintained in specific increments so that all modules would be compatible with a given basic grid form thus permitting maximum density. A small step is molded on the bottom of the module which permits visual inspection of the module side of the

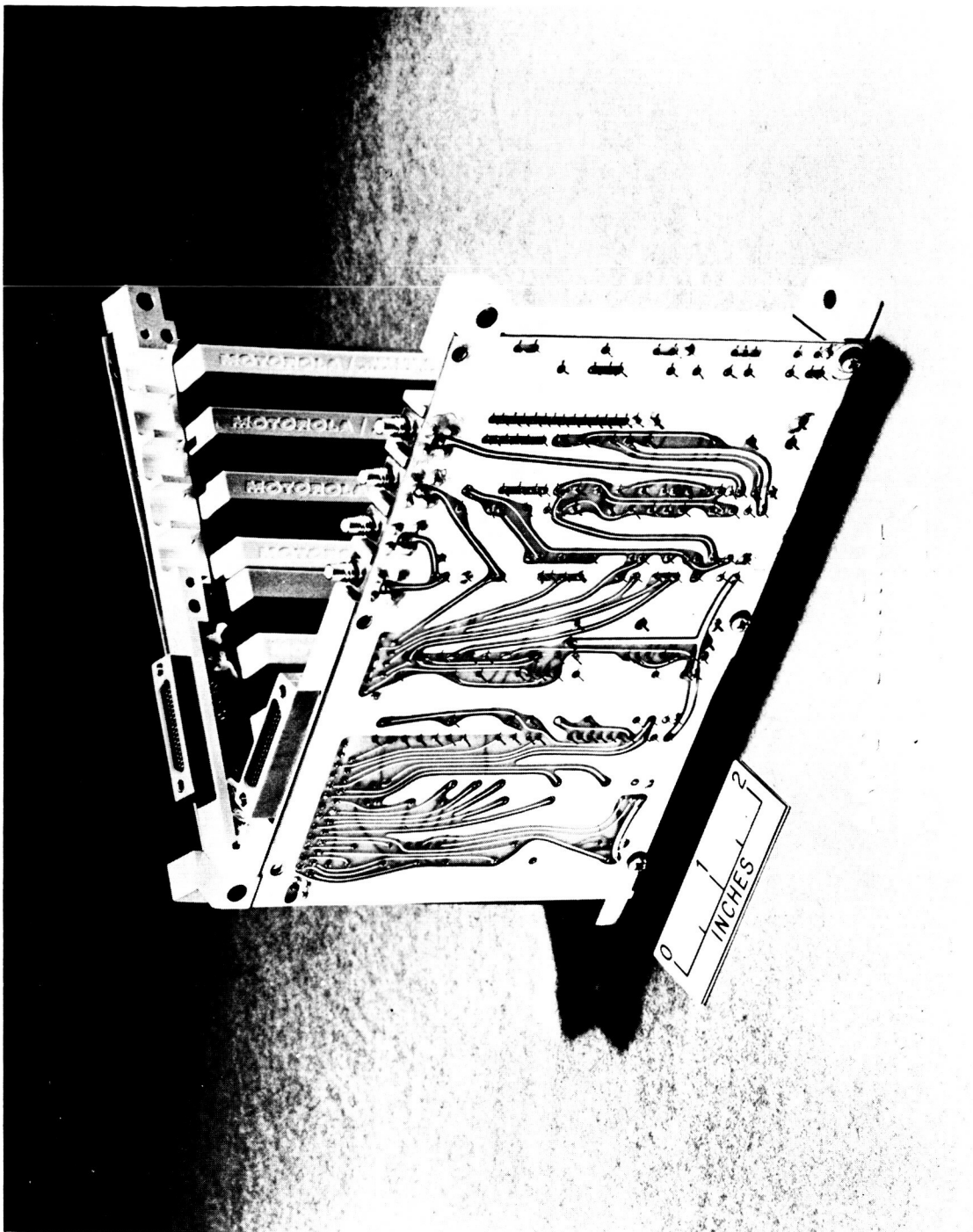


Figure 9. Example of Interleaving Modules

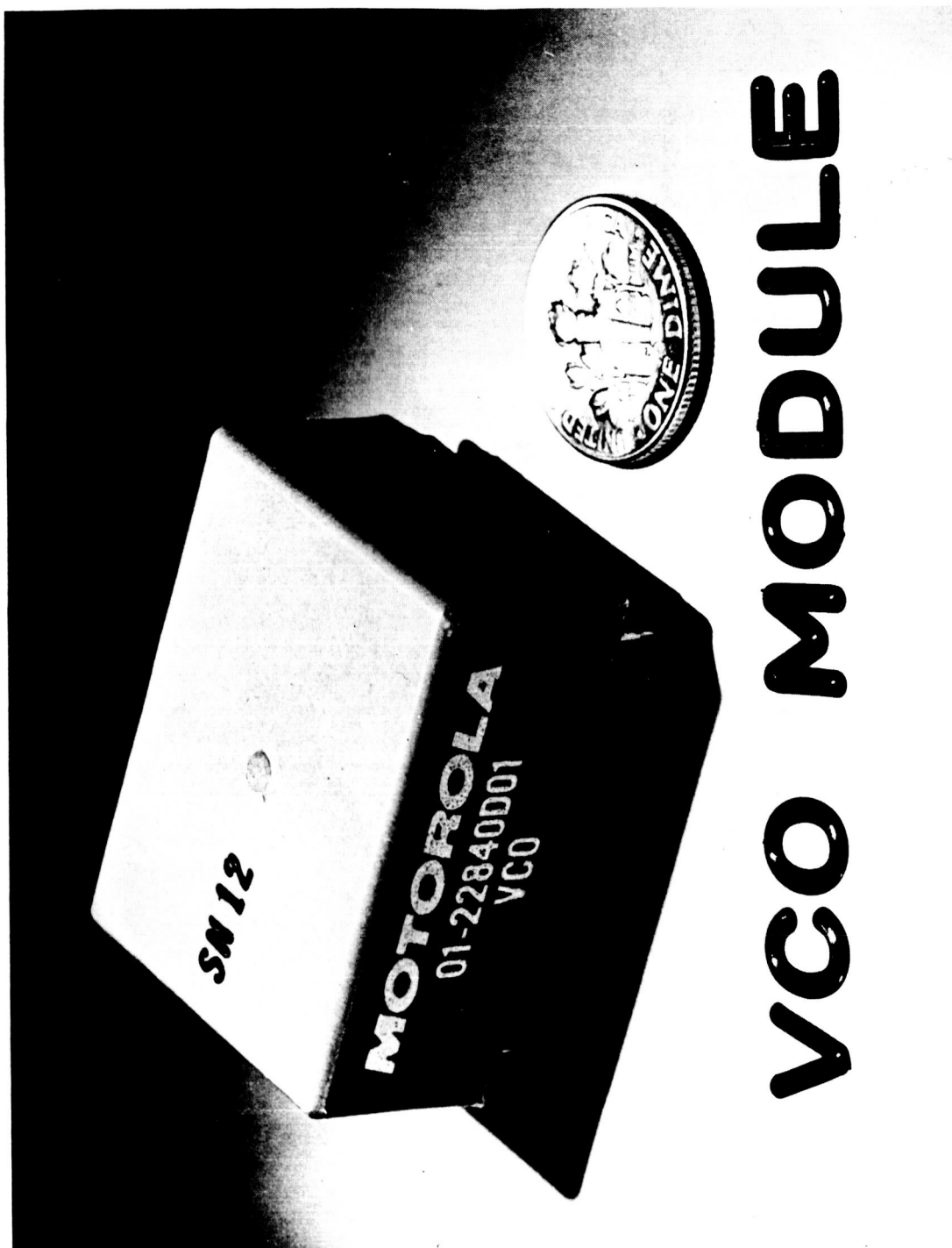


Figure 10. Typical Module



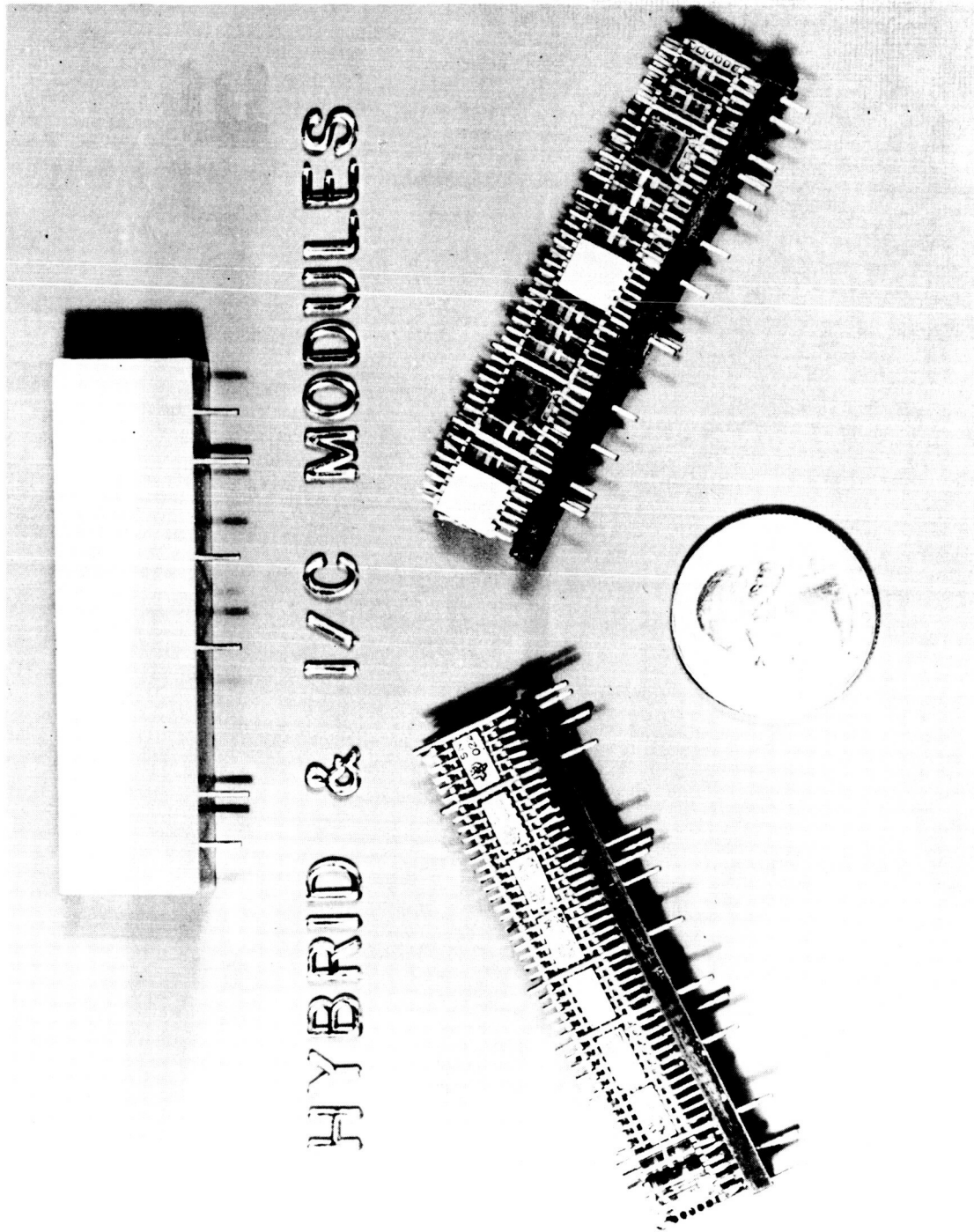


Figure 11. Typical Module

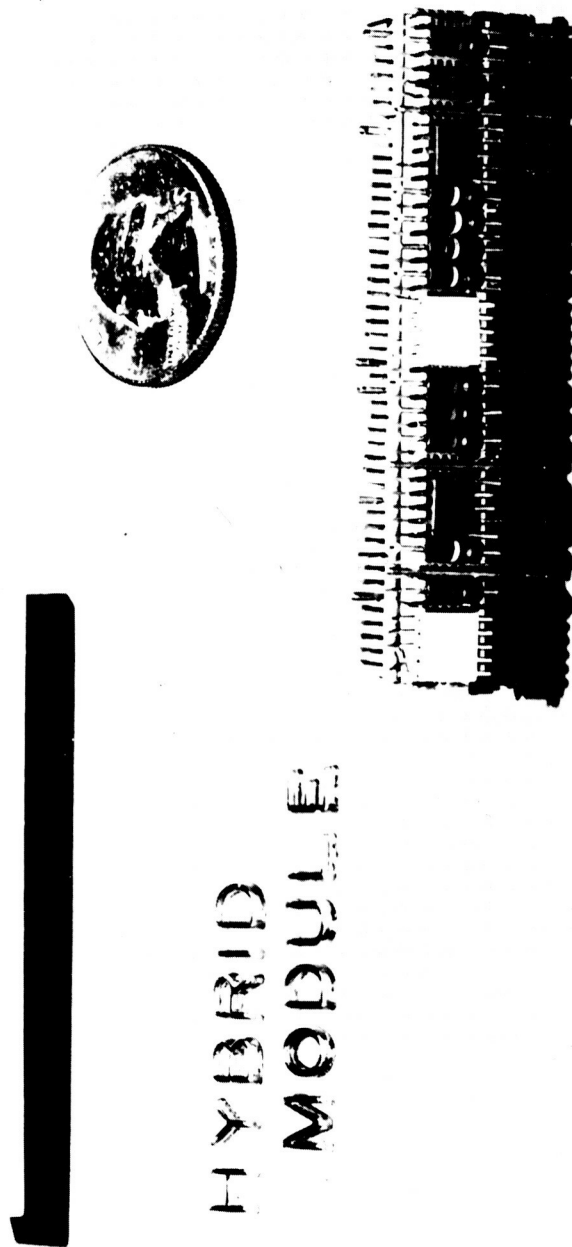


Figure 12. Typical Module (Micro-Harness)

solder joint and facilitates removal of the module for maintenance. The ability to inspect the solder joints is further enhanced by the alternate spacing of the modules to provide for the nesting of modules on each of the two boards when they are placed back to back. This alternate spacing also provides extra space on the printed-circuit boards for the printed-circuit wiring. By using double sided boards, it is then possible with the nesting technique to have four layers of printed-circuit wiring for interconnecting, plus the extra board area at virtually no loss in total parts density. Modules are flow soldered to the mother board.

Structural rigidity is achieved by putting contact adhesive on the tops of each module on the board area between the module. Then when the two assemblies are nested they form a rigid truss similar to a honeycomb panel. The adhesive used was a methyl polysiloxane developed for a high adhesive strength without sacrificing high temperature or electrical properties of standard silicones. The adhesive has a temperature range of  $-100^{\circ}$  to  $500^{\circ}\text{F}$ , provides a rigid bond under vibration but can be separated for maintenance with sustained pressure, and can be scavenged by using a ball of the adhesive material similar to removing rubber cement.

The wiring from each printed-circuit board of the "book" assembly is brought through a right angle and potted to the back of a conventional connector.

Epoxy used for potting modules utilizes a microsphere filler which gives a specific gravity close to water. Other techniques used in different types of packages include a transparent seal guard for a hybrid board module to facilitate visual access for repair.

Motorola has also found it quite advantageous to make serious computerized studies of the thermal problems in modules. The theoretical results have compared quite favorably with empirical findings from the constructed modules.

#### b. Micro-Harness

Another development at Motorola has been that of the Micro-Harness or high density packaging of integrated circuits in flat packs. Present techniques can handle any of the current types of flat packs, i. e., 10 to 14 leads, and can also accommodate some discrete parts. The modules resulting from these techniques are compatible with the packaging system described above. Figure 12 shows a hybrid module constructed along these techniques. The basis for this structure is an etched circuit (Micro-Harness) made up of from three to six layers of a single-sided etched mylar. A basic grid work is formed of two-mil kovar on 50-mil centers. The conductors extend beyond the

insulating film similar in appearance to the leads on a flat pack. The layers of circuit are then placed in a U-channel with the desired conductors extending beyond the edges of the channel (Figure 13). The integrated circuits are then placed in the U-channel on top of the Micro-Harness layers and the integrated circuit leads can be welded directly to the appropriate protruding conductors from the Micro-Harness. Two of the channels are placed back to back and can be interconnected with jumpers. Opposed electrode welding is done utilizing the advantage of one type of material thus simplifying the weld station setup. External connections can be pins or a connector as desired, and the design includes provision for the use of a T-shaped heat sink between the two back-to-back channels and at their base. The complete two-channel module can accommodate twenty 10-lead flat packs or fourteen 14-lead packs. Motorola claims this technique gives the advantage of multi-layer circuitry while eliminating the disadvantage of blind connections. In this type of construction every connection is visible and can be inspected.

A further technique developed by Motorola provides a convenient method for clamping the integrated circuit packages to the layers of Micro-Harness for a pretest before actually welding them. While this packaging technique does not achieve maximum density it does reach a relatively high density and is comparatively inexpensive with respect to other modular approaches for "one-of-a-kind" modules. Further, production of the Micro-Harness is less expensive and less demanding with respect to tolerances than the conventional multilayer printed-circuit boards.

#### c. Radio Frequency Modules

Motorola has also developed a unique technique for packaging radio frequency circuits. This construction is somewhat similar to a cordwood type and is in an external modular form compatible with the modules discussed above. One example of this type of module is shown in Figure 14. The aluminum base is channeled to receive the cover. The base is also covered with a layer of copper for a ground plane. The copper is etched away only where it is necessary to drill holes to bring out a pin from the circuit. A silver-filled epoxy is used to bond the cover to the base. Perhaps the most unique feature of this assembly is the use of a "dry fluid" for the potting agent of the module. This potting agent which pours like water consists of 30 to 300-micron spheres with a molecular coating of uncured epoxy on each one. It has been especially designed for corona suppression. The module can be filled with the epoxy, tested and adjusted for circuit performance. After the module is completely tested and ready for release, heat is applied

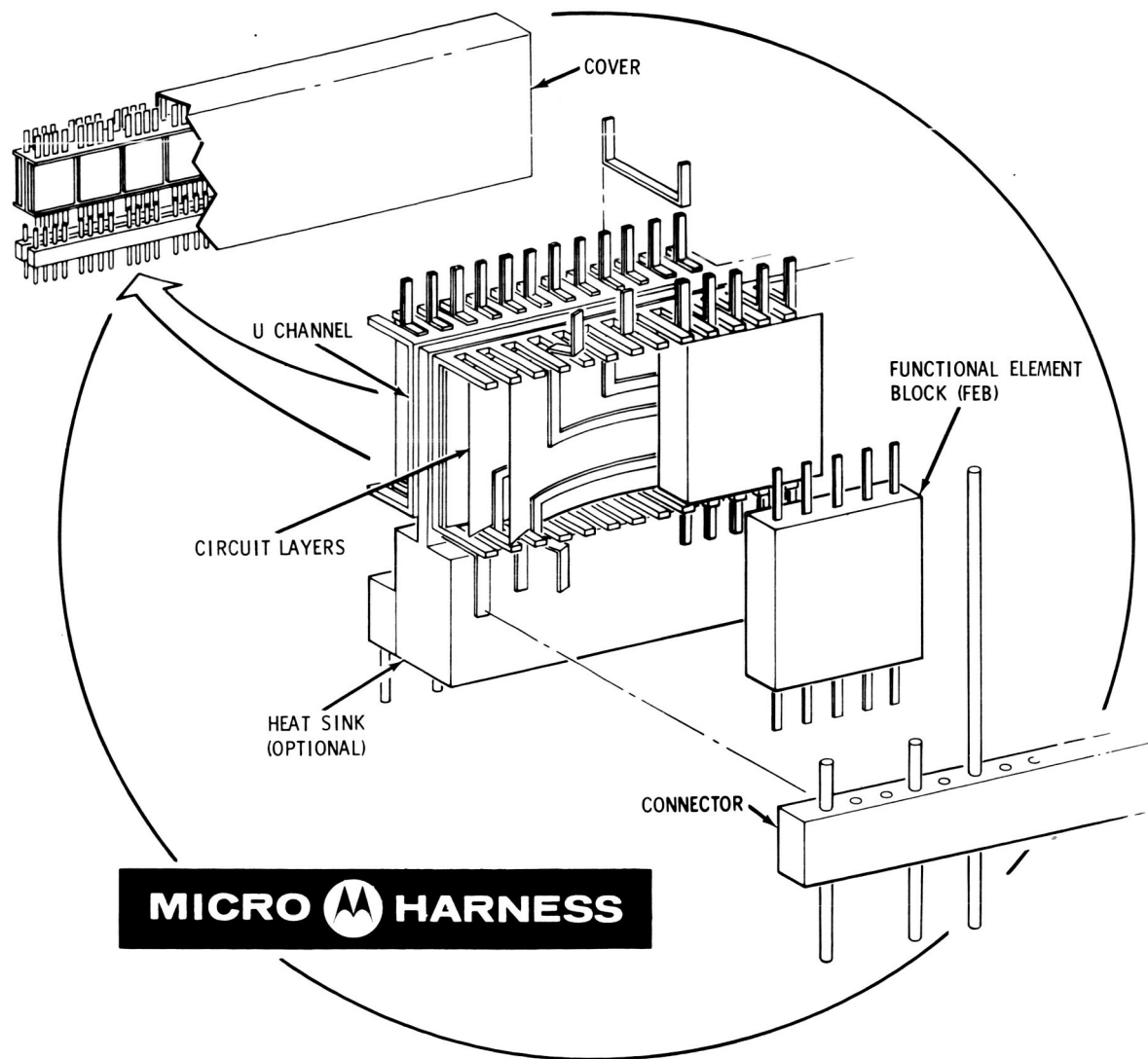


Figure 13. Details of Micro-Harness Construction

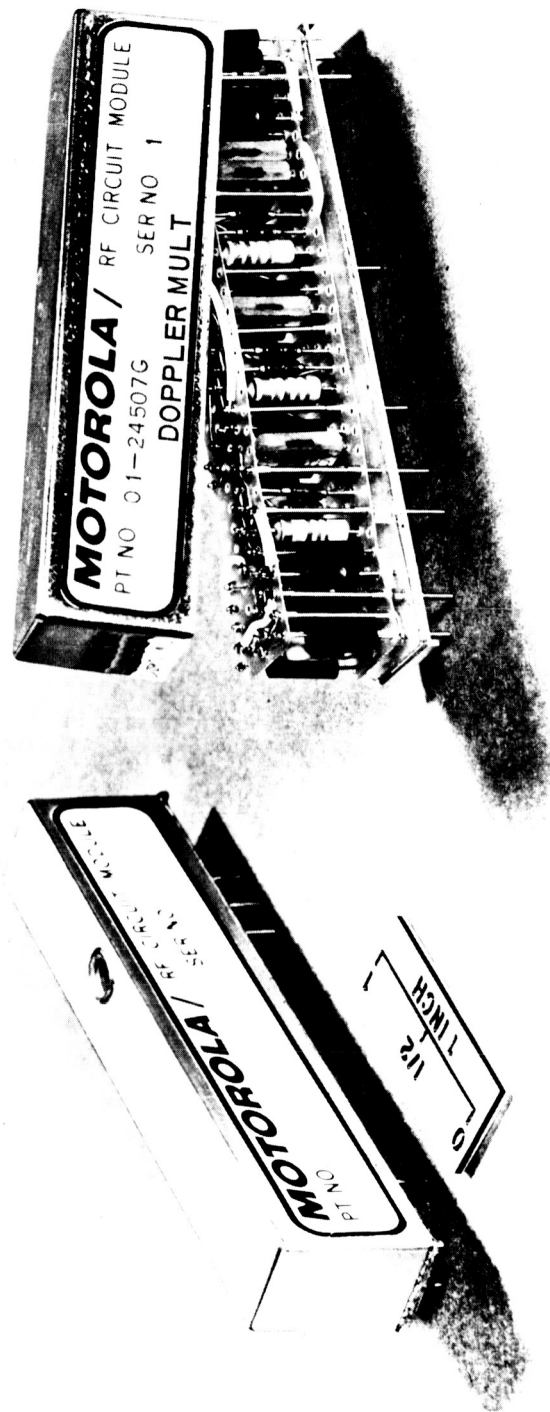


Figure 14. Radio Frequency Module

to the unit which cures the epoxy making a solid potted module. Since each module is different, the straightforward technique of hand wiring and soldering is used for the interconnections at the end of the parts as may be noticed in Figure 14.

Another typical packaging scheme by Motorola is exemplified by the discrete part radio frequency transponder package. This is constructed on a printed-circuit layout oriented to a dip-brazed module frame. The frame is tin plated and dipped in hot oil to protect it from fingerprints. Circuit areas are partitioned with leads from the printed-circuit board serving as board anchors and a ground distribution to the chassis ground, and helping heat conduction. The design permits an intermixing of unencapsulated cordwood modules and basically is hand soldered. The ground plane of the printed-circuit board is coated with a silk-screened epoxy-solder resist to prevent solder bleed over.

The entire unit is foamed with six-pound density NOPCO8206 rigid potting compound. One of the problems is to achieve a uniform foam density thus avoiding variations in circuit characteristics. This is accomplished by using a dispersion plate and free foaming. A rubber pad is applied which permits the ground pins and the frame edge to protrude above the potted region. An epoxy conductive paint is used to coat the entire top surface of the potted module including the frame, pins, and partitions. The resulting larger modules can be stacked and bolted to a base in two rows including a compressed vibration pad. The assembled modules are then interwired point-to-point and harness brought out. It is reported that the use of a printed circuit approach for the basic module assembly saves one-fourth of the assembly time over point-to-point wiring and eliminates the mistakes common to hand wiring.

#### d. TO-5 Can Assemblies

A variation of the book-type construction was based on the use of TO-5 cans where 68 units could be placed on each board. The layout also provides for including discrete parts. The printed-circuit boards are mounted in a die-cast frame.

#### e. Connection Techniques

Considerable investigation has been conducted in developing different techniques of wiring from the printed-circuit board to the external connection of the book-type package. This has included the use of flexible wire from the boards to connectors (as many as six 37-pin connectors), the use of prewired connectors, and the use of edge-type

connectors. A technique for using prewired connectors consists of stripping the wires as needed and using a guide plate to hold them in place while the back of the connectors and the wire formation is potted. The wires are connected to the printed-circuit board by wave soldering and the cables on the bottom of the board are encapsulated in RTV. Silicon flex cable is also used for joining two boards where the donut shaped connection points in the boards are staggered to permit 15-mil centers. A short preformed cable can be dropped in the center of a double-size board, wave soldered in place, and the board cut in two and folded together. In general, the preference is for opposing-electrode welding rather than parallel-gap welding or soldering. Cross-wire welding seems to be working out satisfactorily.

## **11. NASA -Goddard Space Flight Center, Greenbelt, Maryland**

One project office was selected for a visit to provide a review of an example of satellite packaging. It is recognized that the various satellites have their own packaging schemes and any one is not necessarily typical, but it may serve as an example of one method which has proven successful. The basic direction for the particular example chosen was fixed as much as four or five years ago so a large portion of the packaging cannot be considered the state of the art, but it is, nevertheless, proven. Also the approach has not necessarily been frozen, for studies have continued for changing, improving, and updating the techniques in use.

### **a. Module Construction**

One of the more or less standard techniques is to use welded modules similar to cordwood. In this particular case, an 80-percent copper, 20-percent nickel, 0.020-inch diameter round wire is used for the interconnects, insulated by layers of mylar. The wire will withstand 17 pounds tensile strength and the welds test to 14 pounds. The mylar is 0.004 inch thick. The welded interconnect matrix is built up in several layers of interconnecting wires and mylar as needed. Three submodules measuring one by two by three-fourths of an inch are mounted together to one module interconnect. These larger modules are then mounted to the printed-circuit board. Modules are conformal coated with a modified epoxy dip or by brushing a thin layer of low surface tension epoxy. In this particular application, decontamination for biological cleanliness is essential and imposes many additional restrictions. FPH ECCO foam (urethane) has little outgassing and has been successful in space vacuum.



b. Experimental Package

One of the experimental packages reviewed consists basically of a printed-circuit board with hand soldered discrete parts and conventional connectors. The board is placed in a frame and foamed without any conformal coating (decontamination is not required for this particular application).

In another application, integrated circuits in flat packs are hand soldered while discrete parts are mounted axially to the printed-circuit board. Printed-circuit boards are generally double sided boards. In applications using flat packs for digital circuits, 30 flat packs are placed in parallel, inserted into a holder, and then welded.

c. New Studies

There has been considerable study and experience in working with MOS FET units. Particular attention has been paid to the problem of handling these devices without damaging them because of excess static electricity. It was reported that even with the Zener diode protection many of them are damaged if handled carelessly. Extensive care is taken in providing plenty of grounding, metal screens, grounding for the personnel, electrostatic checking of all the equipment before connecting, and even spraying the glass with antistatic material. Elaborate as the precautions may seem they have proved effective in achieving successful handling of quantities of MOS type devices.

The MOS integrated circuits are used for digital logic in a TO-5 can package of both eight and 12 leads. They are intermixed with discrete parts as needed.

Considerable investigation has also been done using monolithic techniques to develop thin-film resistors. One structure produced 59 transistors and 16 resistors on one monolithic chip. At the present time, dies and masks are purchased and the remainder of the manufacturing is conducted at NASA-Goddard.

12. **North American Aviation, Space and Information Division,  
Downey, California**

The purpose of this visit was to discuss the techniques being employed by an on-going NASA program. The project office visited was that of the SATURN II program. The primary function of this particular project office is the mounting, interconnection, and protection of

subsystem black boxes for a total electronics control system on the SATURN II booster. Specific areas of concern include methods for large scale cabling and cable protection, large housing units, thermal insulation, vibration isolation and damping, abrasion, etc. This project was started 4 $\frac{1}{2}$  years ago using discrete components. Further, it was required that existing equipment be used wherever possible. Thus components were GFP, off-the-shelf vendor items, and some components built in house.

Consideration of this particular project is then the state of the art at the time of initiation, the constraints of a tight time schedule, costs, high reliability, the lack of any significant space requirements, and the requirement to use existing equipment insofar as possible.

a. Miniature Module

One of the interesting in house developments on this program has been the development of a compact connector module. The cable side of a round molded pin connector is welded to a small plate for mounting purposes, discrete parts are fastened to the connector pins, and the other ends of the parts' leads are interconnected and welded point to point. The entire assembly is then potted resulting in a compact module of the same diameter as the connector and approximately twice as long. The same approach can be used with two connectors to provide a double-ended in-line network. The same concept has also been used for parallel in-line splicing of power circuits. For example, a half dozen of these connector modules have been arranged back to back to power distribution boxes, thus providing a number of network elements to yield proper distribution of power to many smaller circuits. A module of this type is quite convenient in that it is quite rugged and very easily replaced. The modules have been valuable in providing auxiliary networks needed to interface the various conventional modules from GFP and vendor stock.

b. Cabling

Cabling and harness have been one of the major considerations in this installation. The high current conductors produced a large field, making it necessary to minimize pickup in the signal circuits which was done by developing a helical lay in the cable consisting of four turns per foot which effectively nullifies the field from the high current conductors. Generally, the cables are covered with an external braid of nylon and fiber glass. These steps were necessary to restrain the helix construction, to insulate from engine heat, and to provide abrasion resistance.

c. Potting Compounds

Stycast is used for potting entire functional assemblies. Urethane foam is injected into some assemblies to hold lightweight wires and parts; however, it is not a good moisture seal. RTV in a putty-like consistency is used to cover terminals and stakes for moisture protection where the ordinary conformal coat would tend to pull off the sharp corners. A similar material is used as a heat protector over some of the harness wiring and connectors.

d. Subsystem Packages

Most of the standard components have been placed in large subsystem containers displaced radially around the apron on the bottom of the SATURN booster. These large containers are wedge shaped being approximately 5 by 3 $\frac{1}{2}$  feet and tapering down to 2 $\frac{1}{2}$  by 1 foot. In general, construction for these containers is a honeycomb sandwich approach. Most of these subsystem containers are filled with nitrogen and some are pressurized. Conventional cabling is used from the components within the subsystem box to external connectors where it interfaces with the harness in the booster. Mechanical vibration and acoustical noise have been problems. Frequently, the components obtained would not meet these environmental requirements, thus requiring the project office to do further investigation and design of necessary isolation.

Generally, heaters are used when it is necessary because of cryogenic fuel problems, and insulation is used for normal flight temperature control problems. Usually, the subassemblies or furnished components are qualified as units, and then the entire subsystem container is requalified.

**13. Philco Western Development Laboratory, Palo Alto, California**

Philco Western Development Laboratory is involved in electronic packaging on various programs such as Alsep, subsystems for Mariner 69 and Pioneer, an experiment for APOLLO, etc. Technologies include metal frame, strip line and cavity construction for radio frequency systems, and planar and modular arrays for integrated circuit flat packs.

a. Radio Frequency Subsystems

One approach is to use the basic T-frame structure on which to build a module. Conventional parts are attached to the frame

with silicon cement rather than supported by their leads. Shrinkable polyolefin tubing and feed throughs are used in the frame member for direct point-to-point wiring. An example of this construction is shown in Figure 15. Basically, the power circuits are on one side while the radio frequency circuits are on the opposite side of the member. The entire package is filled with Upjohn's CRP-17 polyurethane, free blown at a density of two pounds per cubic foot. The basic T-frame structure is  $2\frac{1}{2}$  by 1 by  $\frac{3}{4}$  inch; however, the length can vary as noted in Figure 15, for convenience of the particular circuit involved. The base plate for the structure is produced by automatic milling from a solid aluminum piece. The external pins from each module are fed through glass feed throughs in holes in the base plate. Point-to-point hand wiring is used for the interconnects.

The base plate can then be bolted securely as desired. It should also be noted that this construction permits ground ties anywhere that it is desired, and the T-frame acts as an efficient heat sink. A metal cover of 0.005 inch of copper covers the polyurethane potting and contacts the magnesium base. This type of circuit operates in the several hundred megahertz range.

#### b. Multicard Modules

One of the initial concepts at Philco Western Development Laboratory, called the wafer module, was to stack four printed-circuit wafers, each containing four integrated circuits, in one potted package. Riser wires interconnecting the edges of these boards protruded through the header to provide the external connections in a fashion somewhat similar to the RCA micromodule. A hold-down bolt is anchored in the center of the header. This concept has now been expanded to large boards holding several integrated circuits as shown in Figure 16. This module is designed with a fixed height as seen in Figure 16 with variable width and length depending upon the needs of the module. The integrated circuits are parallel-gap welded to the single or double sided printed-circuit boards.

As noted in Figure 16, a copper heat sink can be placed under the integrated circuits and coupled mechanically to heat sink bars which will conduct the heat to the external package. Silicon grease is used on the thermal joints. This technique is said to achieve temperature control within  $1^{\circ}$  to  $2^{\circ}$ F.

These modules are mounted on a mother board through a standard hole grid pattern. The holes in the mother board have a hollow tubelet of 0.030 inside diameter through which the pin from the module passes.

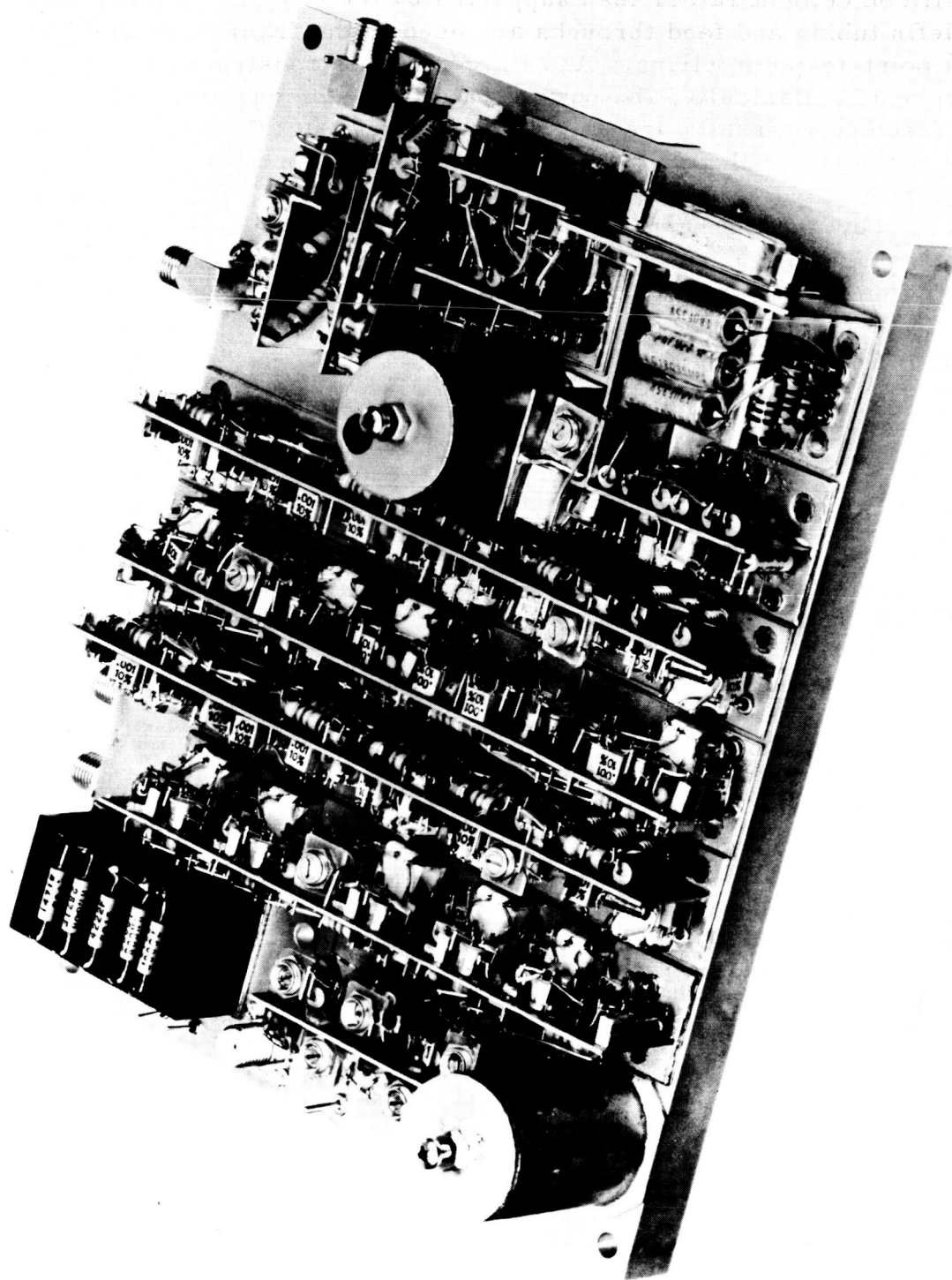


Figure 15. Radio Frequency Module

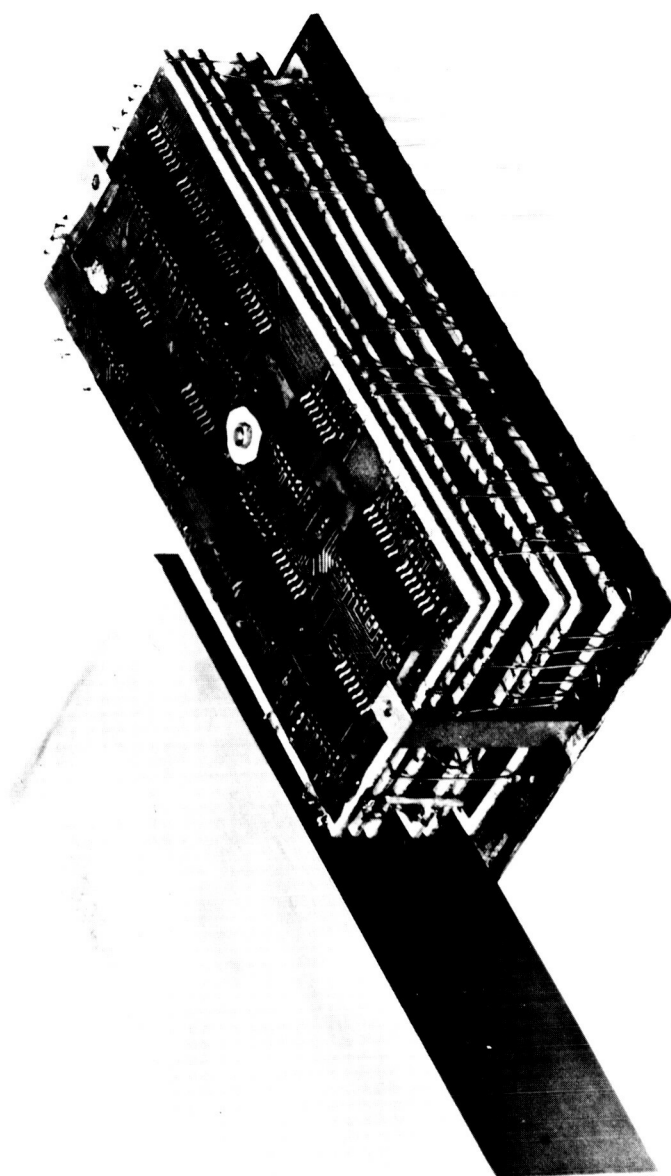


Figure 16. Large Wafer Module

Welded ribbons, which can be cut to permit removal of the module for repair or replacement, provide electrical connection between the tube-lets and the module pins. Some consideration is also being given to parallel-gap soldering to facilitate module removal. The module is bolted through the mother board and chassis to a calculated loading. Connections to the mother board are made by wiring from a connector through a right angle to a header and potting that portion of the wiring. This then becomes a module which is set into the mother board. An example of various size modules assembled in a frame is shown in Figure 17.

A unique feature of the mother board construction is that of constructing a multilayer printed-circuit board by progressive laminations. As each layer is finished, a four-mil coating of "B-stage" epoxy is placed between it and the succeeding layer. Interconnects between layers are welded as each layer is assembled. After the desired number of layers have been assembled, a specific pressure is applied to the entire mother board assembly to create the bond.

Philco also uses the standard cordwood approach for various types of assemblies including shielded radio frequency modules. This is considered a convenient, cheap, time-tested approach for limited densities and limited repairability.

#### c. Hybrid High Frequency Couplers

Another packaging technique used by Philco Western Development Laboratory is the strip line technique for handling high frequencies in assemblies before reaching the wave guide. A machined brass conductor pattern is contained, sandwich fashion, between two slabs of two-pound density foam. This assembly drops into a milled magnesium case to essentially form a solid wave guide. Very few discrete components are used in this construction.

### **14. Radiation, Incorporated, Melbourne, Florida**

The design and packaging of aerospace electronics is one of the principal functions of Radiation, Incorporated. Concepts used in their packaging work were outlined, by personnel in the Aerospace Product Design Section of the Systems Division, as follows:

- 1) Planar configuration with discrete components
- 2) Cordwood modules with discrete components
- 3) Planar arrays of integrated circuit flat packs
- 4) Hybrids of 1), 2), and 3).

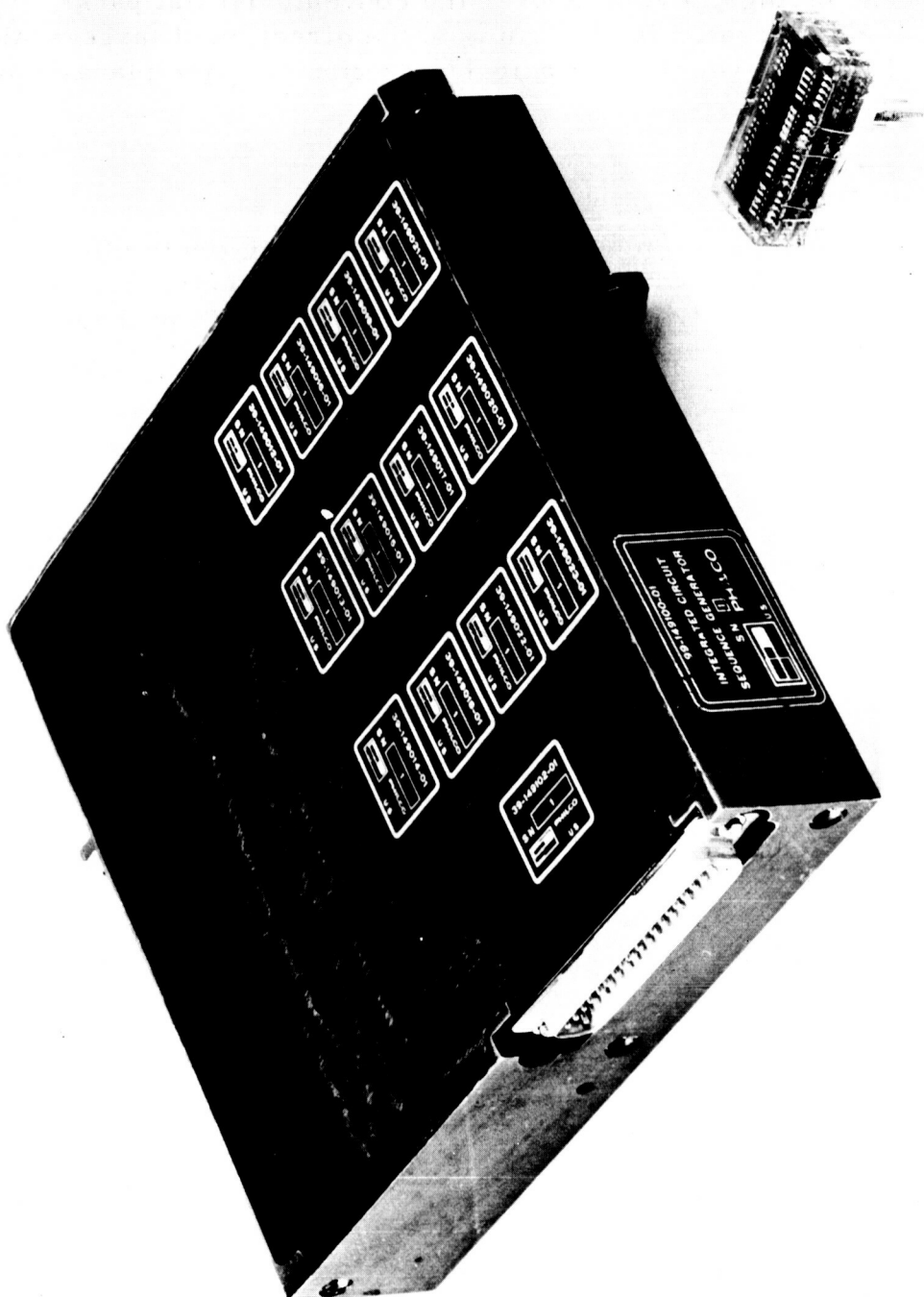


Figure 17. Frame Partially Filled With Wafer Module



In addition to those listed, Radiation, Incorporated, is using their function wafer which is essentially a multichip packaging concept offering a 50 percent savings in volume over the conventional flat packs. Radiation, Incorporated, is also going in the direction of large-scale integrated circuits which offer a 10:1 reduction over the planar flat pack technique.

a. Concept 1

The planar mounting of discrete components offers accessibility for maintenance and replacement of components. However, because of the relatively large volume required in this packaging technique, it is being phased out.

b. Concept 2

The cordwood module of discrete components is perhaps the old standard of Radiation's packaging work. In this method, discrete components are stacked in a vertical orientation between mylar platens, and circuit interconnections are made by welding nickel ribbon to the protruding component leads according to ribbon routing paths printed on the mylar sheets. Where integrated circuit flat packs are used in the cordwood module, the leads are lengthened by welded on extensions and the flat pack is encapsulated in epoxy to a size compatible with the discrete components. The completed cordwood assembly is potted in polyurethane foam and has a flat configuration; i. e., the length and width are about three times the height. Eight of these potted assemblies are mounted by soldering to a plated-through hole, printed-circuit board. Their studies have shown that plated-through holes are superior to feed-through holes, having successfully withstood 80 g's vibration, thermal shock, etc.

Connection from the individual boards to the input-output connectors is made with hard wiring. Since one of Radiation's prime objectives is maintainability, they avoid use of the mother board concept. The hard wiring used is Number 24 (or 26): 19 strands with a service loop large enough to permit a board to be extracted from the stack and serviced. RTV 521 molding material is used to pot the connections of the hard wire to the printed-circuit board to prevent breakage and provide environmental protection. Some packages use, instead, a strip connector to engage the wiring with the board.

An alternate method has the hard wiring placed in rather tightly (without loops); thus, the stack of boards, interconnected, can be fanned open like book pages for required accessibility. Urethane foam is used

to pot the whole volume behind the input/output connectors to eliminate wire movement (and breakage) and to offer some environmental protection. The wiring run between the board and connectors is not cabled in any manner; they discovered that lacing these bundles contributed to wire breakage.

The printed-circuit boards thus completed and having been equipped with locator devices are compressed into a stack between radial-ribbed aluminum end plates and held with a center-through bolt. This stack is subsequently mounted within a metal housing on rubber vibration isolators which provide a "floating" arrangement for the stack.

Radiation, Incorporated, has successfully used the compression-packaged, foam-encapsulated welded module approach in several space applications. Of interest is the fact that the foam potting is prestressed so that a neutral stress condition exists when the board is in the stack. The soldering of foam-potted-module leads is done under compression for the same reason. Where power dissipation requires it, an aluminum plate is potted in at the surface of the module to provide the necessary thermal conduction; the heat producing components contact this plate. Radiation, Incorporated, has also used aluminum filled foams with some success.

The housing used in the LEM vehicle is milled from a solid aluminum block to an 0.090-inch wall thickness by a tape programmed machine. The cost is reported to be comparable to that of a cast housing, and the quality is much better. A similar approach was used on a package for the SATURN, Block 2. Close proximity screws are used to secure the lid in lieu of a radio frequency interference gasket. A 10-day humidity requirement for an APOLLO Block 2 package together with a thin-walled housing, which could not withstand 15 pounds per square inch, resulted in a novel breathing compartment development. This compartment, a silica-gel-filled cell functions both as an active and a passive moisture filter; i.e., it has valves to the outside world and screened ports to the interior of the housing.

### c. Concept 3

Radiation, Incorporated, uses six-layer printed-circuit boards (which they consider optimum) for the planar mounting of integrated circuit flat packs (Figure 18). The six-layer board with plated-through holes and electro-tinned solder pads is made in house. The flat pack leads, having been pre-dip-tinned, are attached to the board by reflow soldering. Early work consisted of soldering the leads one at a time. Presently, Radiation, Incorporated, is soldering seven leads

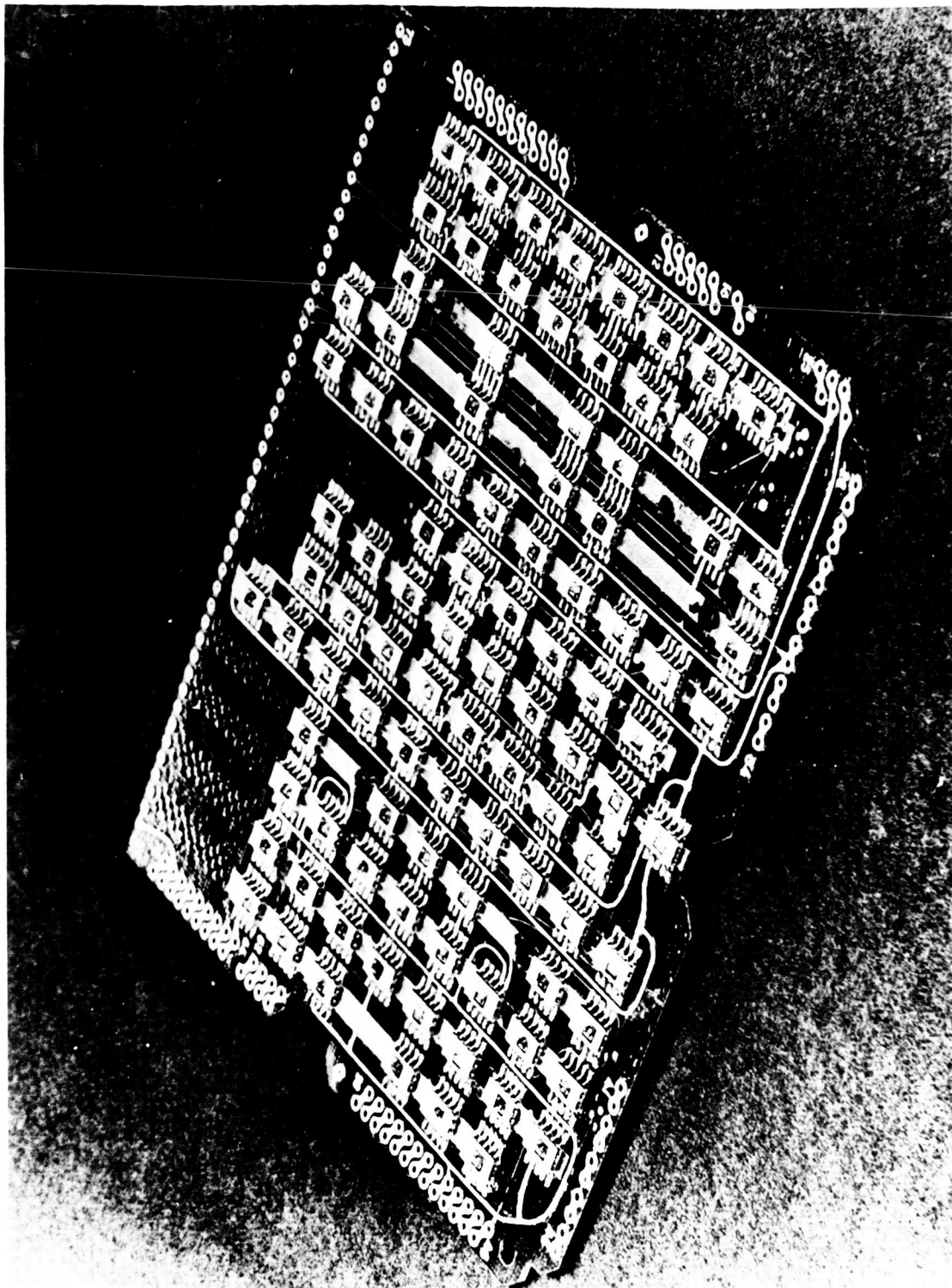


Figure 18. Planar Mounting of Integrated-Circuit Flat Packs

on one side of the flat pack at a time, and is developing an automated machine which feeds, places, and accurately positions the flat pack on the board and holds it in place while all 14 leads are soldered under an inert gas blanket. The machine, which will be marketed under the label of RADIBOND, can handle 24 different types of circuits in three operational modes; fully automatic, semiautomatic, and manual. The ratio of time used by a man doing the soldering operation to the fully-automatic operation of the machine is about 200:1.

Radiation, Incorporated, has gone in the direction of surface soldering of flat pack leads due to the large number of packs per card, 100 to 200. The bent-lead flat packs were tried but found to be unfeasible: while an apparent gain resulted in surface density, the multilayer circuit boards became too complex. A mylar tape strip is used to insulate the printed-circuit board surface underlying the metal capped flat packs. Urethane foam layers are affixed to the bottom side of the circuit boards to furnish a compressible spacer between the boards. The foam is contoured to fit the flat packs on the adjacent board.

Hard wiring is used to connect each board to its own input/output connector. Interconnections between the boards are provided by rigid vertical riser wires which pass through AMP miniature spring sockets around the periphery of the circuit boards (Figure 19). This technique simplifies board layout and contributes to ease of assembly, convenient electrical checkout, and rapid repair capability.

#### d. Prototype Development

Within this general concept, a double-sided printed-circuit board which has many parallel conductor paths across the width of the board on the other side has reached the prototype stage. Plated through holes occur at every opposed crossing of the conductor paths. Flat packs can be attached anywhere on the board, and the paths interconnecting the circuits can then be defined by burning out unwanted connections with a taped electron beam.

Another developmental item resulting from a feasibility study is a plug-in micromodule that uses recessed Cannon  $\mu$ D series twist pin connectors. The recessed pins mate with protruding tubelets mounted on a printed-circuit mother board. The micromodules contain flat packs in a pancake stack configuration. These micromodules have never been in production.

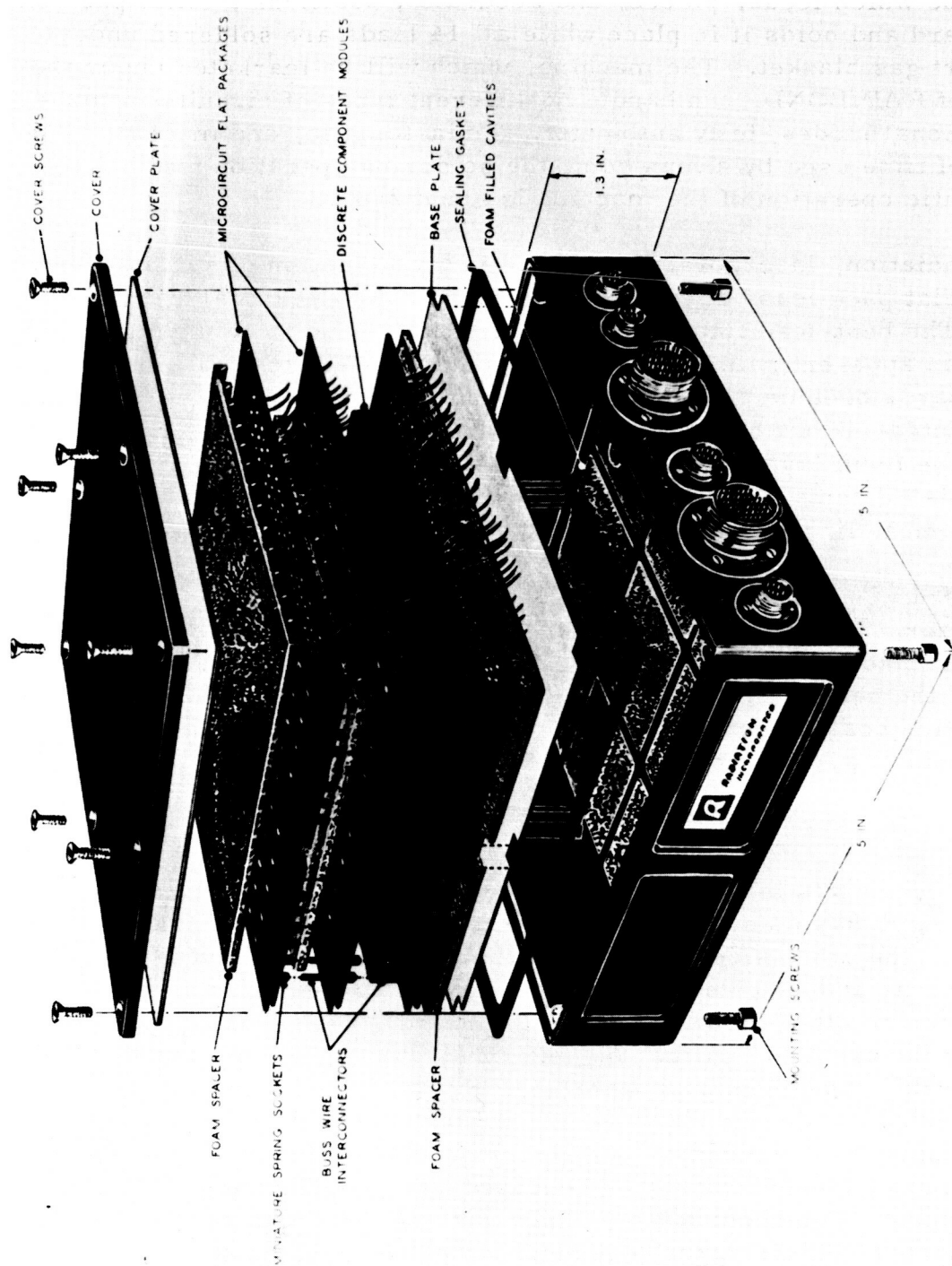


Figure 19. Mechanical Assembly

e. Large Scale Integrated Circuit

This development is a three-inch square ceramic mother board to which 70 integrated circuit chips are alloyed. Conductor bus lines consisting of electrodeposited gold in five mil square grooves are located on each side of the board with all lines on the back running normal to those on the front. Where required, connections are made from the front to the back by gold-filled through-holes. Flying gold wire leads, ultrasonically bonded, interconnect the chips and the bus lines. Overlaying the mother board is a ceramic "tunnel" board that is recessed above each of the 70 integrated circuit chips to provide clearance for the flying leads. The tunnel board serves as a structural member of the package, damps the flying leads for vibration purposes, and provides both thermal isolation between the chips and microphonic isolation between the chip circuits. These two ceramic boards (mother and tunnel) are sandwiched between aluminum plates that have a hard anodized coating on the outside surface for resistance to alpha and gamma radiation and a mica-glass coating on the inside for electrical insulation. A treated aluminum edge-wrapper holds the sandwich together while it is bonded into a monolithic package with silicon seals and heat. The completed package, measuring approximately 3 by 3 by  $\frac{3}{16}$  inch, uses printed cable wiring to the input/output connectors. Twenty of these packages comprise a complete telemetry system. The prototype system, including the mounting chassis, had approximate dimensions of three by four by five inches. This approach offers a 10:1 package reduction from the planar flat pack technique. A more dramatic comparison is that eight relay racks would be required to house this system if built of discrete components.

**15. Sandia Corporation, Albuquerque, New Mexico**

The Special Projects Division of Sandia Corporation is concerned with electronic circuitry for the VELA satellites. High reliability is the prime consideration. Their success in this realm is attributed to the following design criteria:

- 1) Tight specifications on design and parts
- 2) Great care in the initial selection of vendors and components
- 3) Limited list of proven components
- 4) Relatively simple circuits
- 5) Rugged mechanical design and housings
- 6) Skilled production labor
- 7) Close cooperation with semiconductor manufacturers

- 8) Reticence toward integrated circuits for volumetric savings alone
- 9) Goal of zero maintenance.

Because of the rather special application and requirements for their units, Sandia engineers have paced the development of their designs, and feel that their approach is conservative and only moderately dense. The units which Sandia builds contain many different types of functions of card modules and relatively few of an individual type. Sandia engineers rely heavily on experience, good engineering design, and skilled personnel for their winning combinations

a. Initial Planar Designs

Sandia's early designs used planar mounting of miniature discrete components on double sided cards having gold-plated, copper-conductor patterns with plated-through holes. Assembled, the cards were 0.3 inch thick, one and two inches wide, and 1.5 inches high; components were hand soldered to the cards. All plated-through holes not occupied by component leads were reinforced by a soldered-in wire. A polyurethane laminar X500 conformal coating provided environmental protection. These boards plugged into a two-layer mother board through ELCO spring fork connector fingers mounted in line along a facial edge of the board. Multilayer mother boards were sometimes used but were not preferred. Checkout, at this point of assembly, was computer automated.

Housings for the mother/daughter assemblies were machined from solid aluminum blocks, the finish dimensions being about four inches square and two inches high. An optional card guide arrangement was incorporated in the housing design, consisting of thin partitions of polyurethane foam or nylon with milled vertical card slots. These partitions could be positioned to allow one long card or two short cards in a given row on the mother board. The underside of the housing lid was equipped with a foam pressure pad which served to hold the cards down to the mother board. Designed for a 100-g vibration requirement, every unit was flight test qualified to a level exceeding the specification.

The input/output connectors to this housing were located around the periphery of its base as needed. Cannon twist-pin (Centipin size) connectors were used. Before installation, the connectors were prewired with lengths of polyolefin-insulated, 26-gage solid wire, each of which had a shrinkable-spaghetti sleeve installed at the soldered joint. With the connectors installed, the wires were routed in cable groups to the various terminal points on the mother board and soldered. Terminal

points on the mother board were the rear extensions of the ELCO spring fork connector fingers. The cable groups were laced with nylon braid to secure them and finally the whole area was conformal coated. Most of the interconnects between the daughter boards were provided by the etched mother board with the remaining few being provided in the hard wire level. Thermal wire strippers were used exclusively in the hard-wire installation to eliminate the possibility of nicking the wire thus inducing a possible point of failure; however, shielded wire was used at this level if it could not be designed around.

b. Integrated Circuit Packaging

What has been described could well be termed a basic design since most of Sandia's later developments in electronic packaging are refinements or alterations of this design. Sandia just recently began to seriously use integrated circuits in the current VELA satellite. This is because the high power consumption and high noise sensitivity of integrated circuits were incompatible with their earlier designs. Sandia feels that the electronics packaging industry is still a long way from knowing how to specify integrated circuits and as a partial solution to this problem, they cooperate very closely with the semiconductor manufacturers to obtain exactly what they need. Ground rules for this interplay between user and maker are stringent parametric requirements, availability of variables data, only "cream-of-the-crop" acceptance, and funding aid for new developments and studies.

The early approach to the use of integrated-circuit flat packs was a planar one with the leads parallel-gap welded to inconel-clad boards. Sandia had problems with blowouts and with joint inspection due in part to the use of older generation welding equipment, but were successful to the point of placing a welded system of 290 integrated-circuit flat packs in their Launch-3 satellite.

Currently, Sandia is attaching flat packs, which have ceramic cases and preformed Z-shaped leads, by the reflow-solder technique. Joint inspection has also proven to be a problem with reflow soldering; joints which appeared to be good were found to be weak due primarily to the gold plating on the kovar leads amalgamating with the solder. The joint inspection problem was overcome at one time by a heavy solder coating on the board and several dip-tinning cycles on the leads with intermediate wiping of the molten metal. The solder alloys with the gold, diluting it and effectively removes the gold in solution during the wiping process. Sandia now specifies that the gold plating be put on the flat packs leads such that joint inspection is no longer a problem.



The newest approach to the use of flat packs will have the leads of the flat pack bent at a right angle and hand soldered into staggered plated-through holes in the printed-circuit cards. The cards will have essentially a standardized layout with the eight flat packs, the  $V_{CC}$  and ground buses, and the connector position appearing in the same place on all card types. Only the interconnect pattern will be varied, and this, rather easily and economically. Sandia realizes that this is a less-dense approach than their previous method but consider it to be more reliable, to permit faster assembly, and to allow a better dovetailing of production and parts delivery schedules. In both the Z-bend and right angle bend techniques of flat pack attachment, the integrated circuit case stands off the board so that an insulating tape is unnecessary between the tape and the board. Conformal coating is applied as a final step in either method.

### c. Connectors

Sandia has had no trouble with the ELCO connector fingers when properly installed. This installation requires close tolerance setups during soldering, in the order of 0.001 inch pin-to-pin and 0.003 inch over length of board, so that jigs are used. Experience has taught Sandia that the pins must also be thoroughly defluxed and cleaned after attachment. Sandia originated the idea for and cooperated in the development of the twist-pin connector which Cannon markets. As noted previously, these are used exclusively for the input/output connectors to their black boxes. In accordance with the "basic design concept," the milled outer housings are either scaled up or down in size and structural strength to suit the application. Units have been built for a 250-g vibration requirement.

The systems built for the VELA satellites operate relatively cool and thermal dynamics is a minor factor in their design. Semiconductors are derated 10 to 1/air to vacuum; transistors are operated so conservatively that Sandia specifies the beta parameter at minimum current. One-quarter watt carbon composition resistors are used extensively, but a current move is toward the use of one-eighth watt elements. Ceramic and tantalum capacitors are used.

## 16. **Space Craft, Incorporated, Huntsville, Alabama**

Space Craft, Incorporated, has developed a standardized packaging technique which accommodates 25 different circuits from power supplies to S-band receivers and which is very rugged, compact, and adaptable. An example of their capability is a 100-channel telemetry

transmitter in a volume of approximately one by two by three inches. Space Craft, Incorporated, prefers the 2-D planar mounting technique where all components are in one layer and are interconnected by point-to-point printed-circuit wiring.

Three approaches are used by Space Craft, Incorporated, to their packaging jobs.

a. Approach 1

Miniature discrete components are assembled into high-density cordwood modules, interconnected by welding, and potted in a hard setting epoxy. These units are soldered into place on printed-circuit cards and the input/output connectors are made with flexible printed cabling. The potted cordwood module in this approach is considered an unrepairable throw-away item (Figure 20).

b. Approach 2

Microcircuit flat packs and discrete components with ribbon leads are welded onto printed-circuit boards in a planar configuration. The printed-circuit boards are equipped with Cannon Microstrip connectors along one edge, which plug into mating connectors on a mother board. Another technique uses fingers extended from the daughter boards which are soldered into the mother board. The daughter boards are coated with a hard epoxy on the back and urethane on the front. Where components are soldered to the printed-circuit board, the urethane coating facilitates repair and component replacement. In practice, the daughter board is considered to be the smallest feasible spare part item. Up to 26 daughter boards are connected into a single mother board in this approach. The mother/daughter assembly is shock mounted within a metal housing by compressed rubber pads. Flexible printed-circuit cabling is used to connect the mother board to the input/output connectors (Figure 21).

c. Approach 3

Approach 3 is a larger version of Approach 2 in which the housing and mountings of the individual printed-circuit boards differ. Each printed-circuit board becomes one side of a vibration damping sandwich comprised of a 0.1-inch visco-elastic layer between the back of the printed-circuit board and the aluminum panel. The statement was made that this sandwich had been tested to 2000 g's with no adverse effects. These sandwiches are held in spring loaded slots in a cast-aluminum housing such as that shown in Figure 22, and plug into a

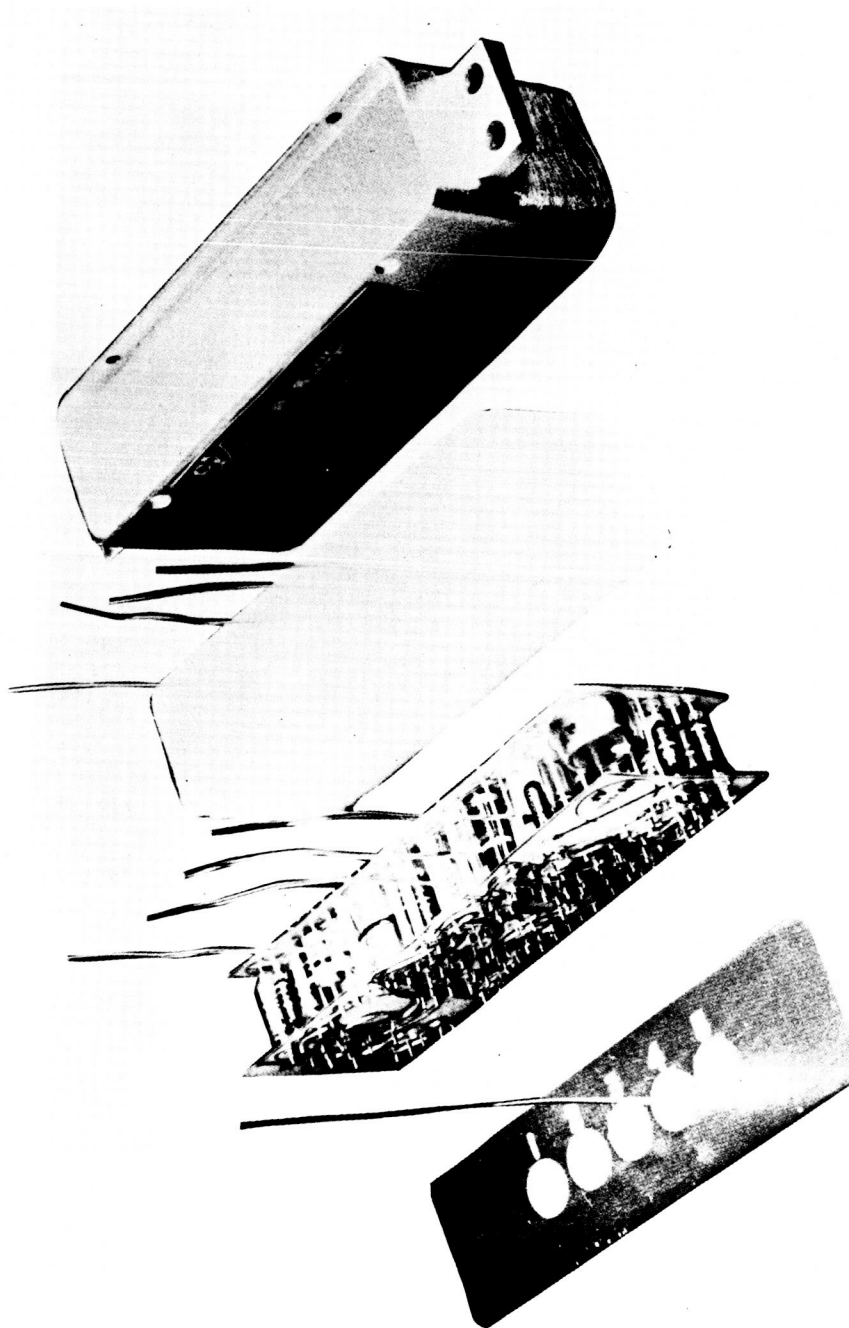


Figure 20. Cordwood Module

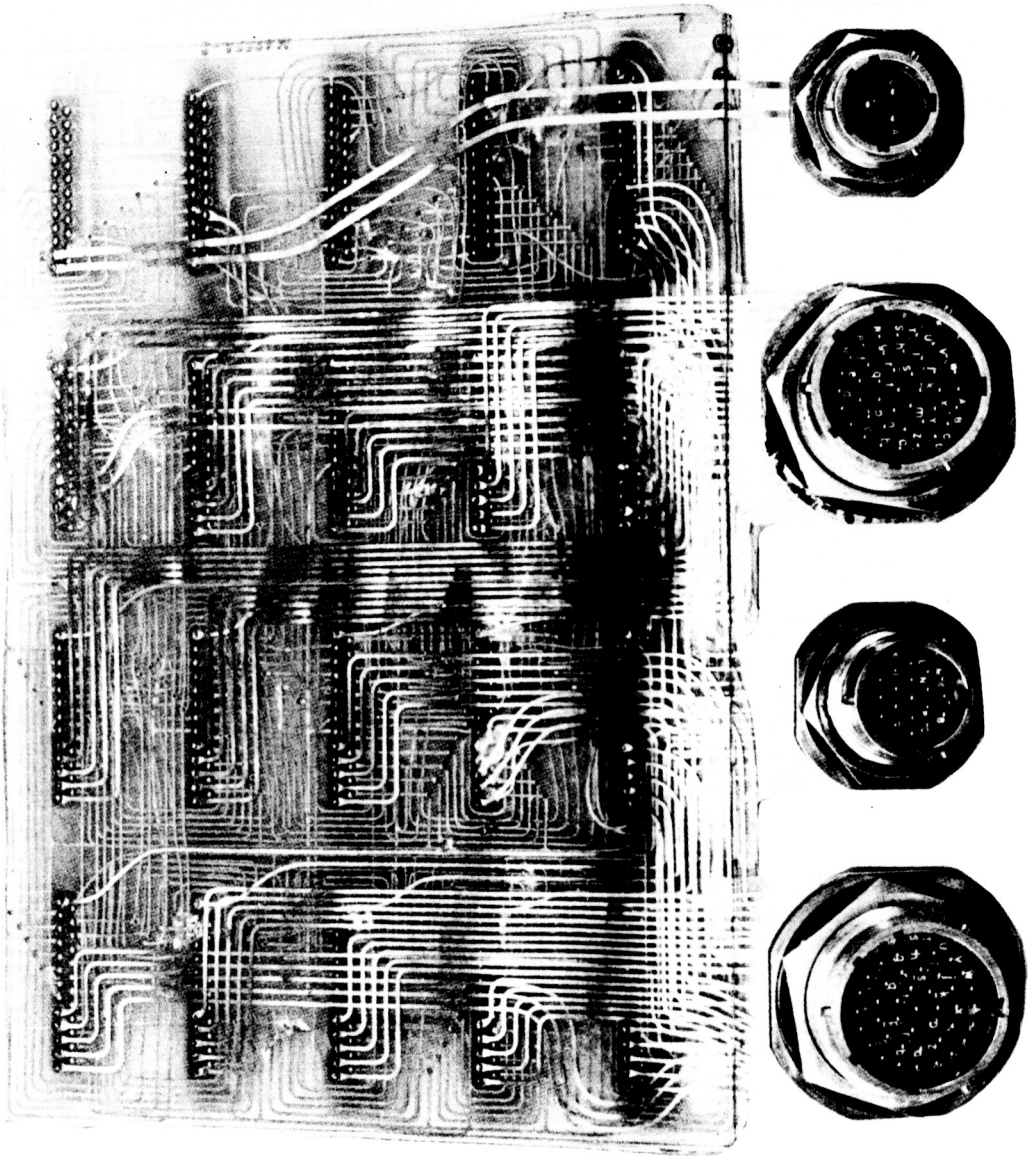


Figure 21. Mother Board Flexible Printed Cabling

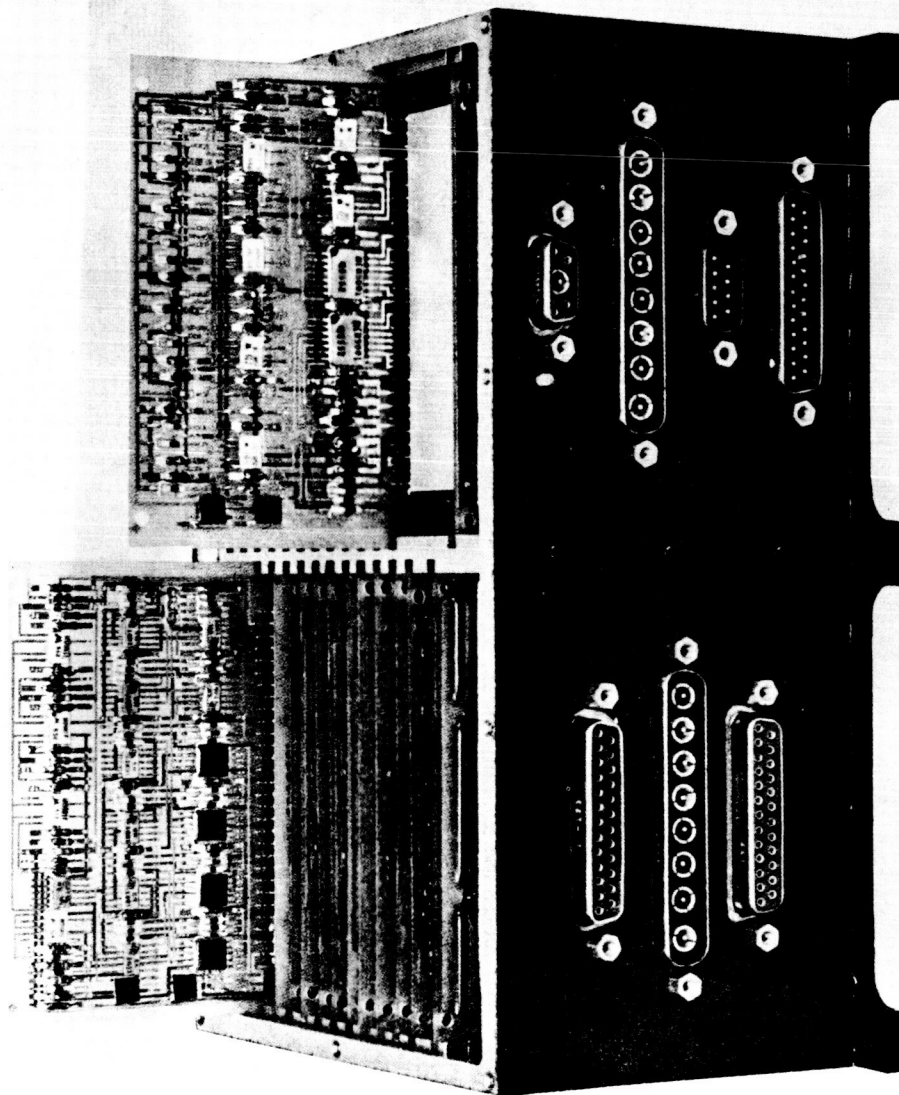


Figure 22. Example Housing and Packaging

printed-circuit mother board. Flexible printed cabling is brought out to the input/output connectors. In this larger approach, radio frequency interference filters are built into the back of the input plugs. Compressed rubber pads float the assembly within the housing, and the unit has been run up to 200 g's with no problems. The housing or outside case is produced in one of the following ways:

- 1) Sand-cast aluminum or magnesium
- 2) Investment-cast aluminum (356T6) as large as 10 by 6 by 5 inches
- 3) Die casting.

Radiographic inspection is used on first production runs of castings only, since experience has shown that once the mold is perfected, production of perfect castings is not a problem. Zyglo inspection is used subsequent to heat treatment of the castings as a check for cracks in the metal.

#### d. Interconnections and Wiring

Space Craft, Incorporated, standardized on welding, manually performed, as the method for connections and interconnections. For high reliability jobs, Space Craft, Incorporated, has developed a method of redundant welding for joints. Pure nickel is used for all component leads, interconnection ribbons, and printed-circuit board foils.

Custom printed-cable wiring is a big item at Space Craft, Incorporated. This approach eliminates wiring error, is light, compact, has no inherent vibration problems, and is competitive with hard wiring in production runs. Another of the advantages of printed cabling is shown by the accessibility of the micro-miniature fold-over module in Figure 23. Space Craft, Incorporated, uses printed-cable runs of up to 60 conductors in a single layer; these evolve into a multilayer configuration for termination at input/output connectors. Encapsulation of the back of the printed-circuit boards and the connectors is simple with printed-cable wiring. Space Craft, Incorporated, designs, but does not make, their printed-cable wiring; however, they do make their own printed-circuit boards.

#### e. Thermal Control

Space Craft, Incorporated, does not rely on filled epoxy materials for thermal conduction in their encapsulated designs. Space Craft, Incorporated, has found that the beryllium-filled materials are

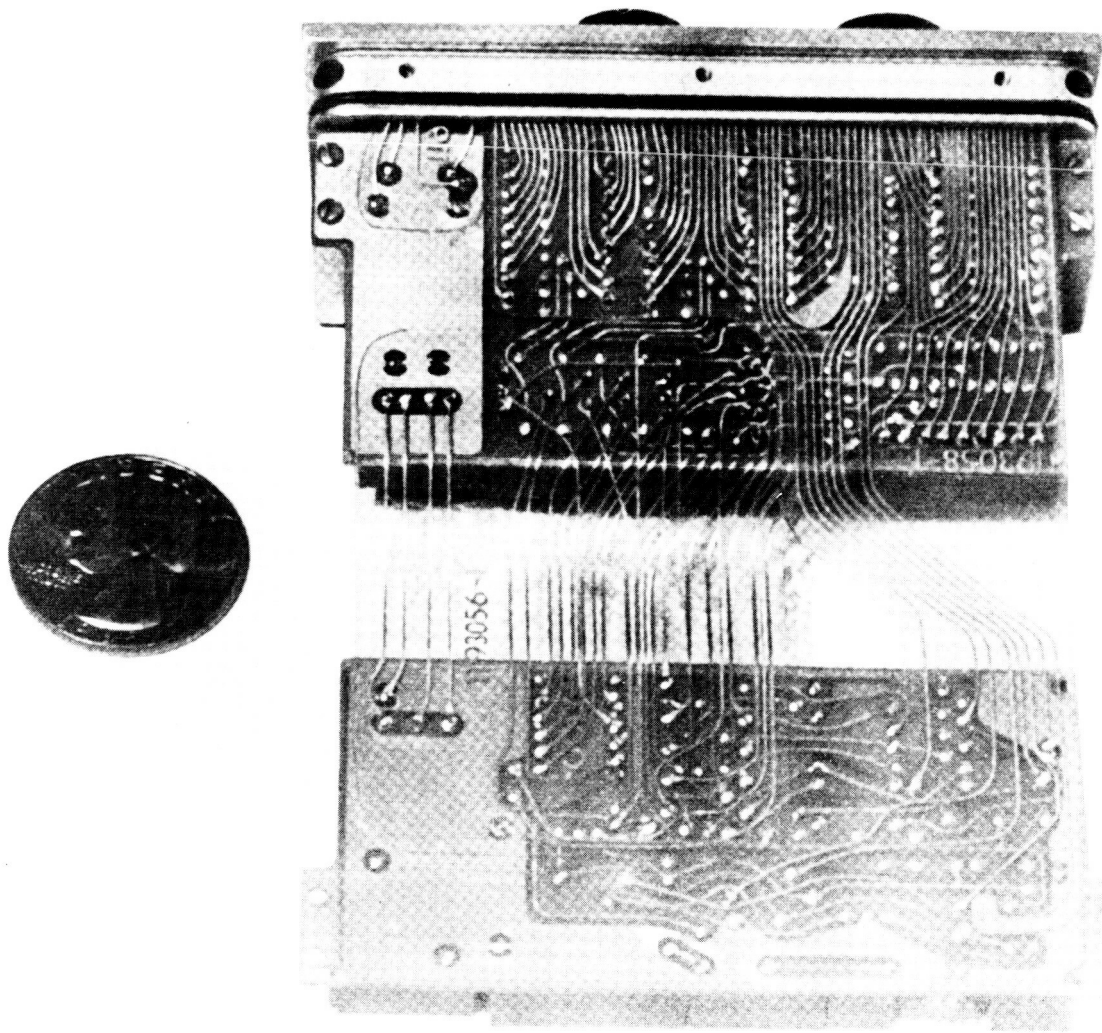


Figure 23. Microminiature Module

satisfactory for this purpose but ceramic materials are not. Nevertheless, they design around the problem by incorporating aluminum brackets which overlay the printed-circuit board where required and contact the outside housing in the board mounting slots'. The printed-circuit board is cut away to allow the heat sink plate to be formed in flush with the board edge.

#### 17. Texas Instruments/Apparatus Division, Dallas, Texas

The Digital Systems Branch of Texas Instruments' Apparatus Division has a broad scope of electronic packaging activities. Their designs include devices for shipboard, ground support, airborne, and aerospace applications. Five major topics, which encompassed their design considerations, were reviewed and are as follows:

- 1) Printed-circuit boards
- 2) Volumetric efficiency
- 3) Miniature connectors
- 4) Secondary connections in the integrated circuit system
- 5) Enclosure design factors.

##### a. Printed-Circuit Boards

The fiber glass G-10 and G-11 material with conductive layers of copper, nickel, or kovar are the basic printed-circuit boards with which the Digital Systems Branch designs. In past work, they had favored the nickel boards with narrow conductor paths, welded nickel ribbon-through connections and welded component leads (Figure 24). Current designs are using the copper-clad boards with etched isolation paths separating broad conductive areas, plated-through holes, and parallel-gap soldering of individual component leads. For NASA designs, the Digital Systems Branch is manually filling the plated-through holes with solder. Single-shot hot-gas soldering of flat packs to the circuit board is presently being evaluated and is expected to be the standard technique in the near future. Reasons given for the changeover from nickel-clad boards and welding to copper-clad boards and soldering were as follows:

- 1) Boards are less expensive to buy
- 2) Circuits are less expensive to make
- 3) Inherent ground plane and shielding possibilities with etched isolation path principle
- 4) Soldering parameters are not as critical as welding parameters
- 5) Much better maintainability of copper/solder system.



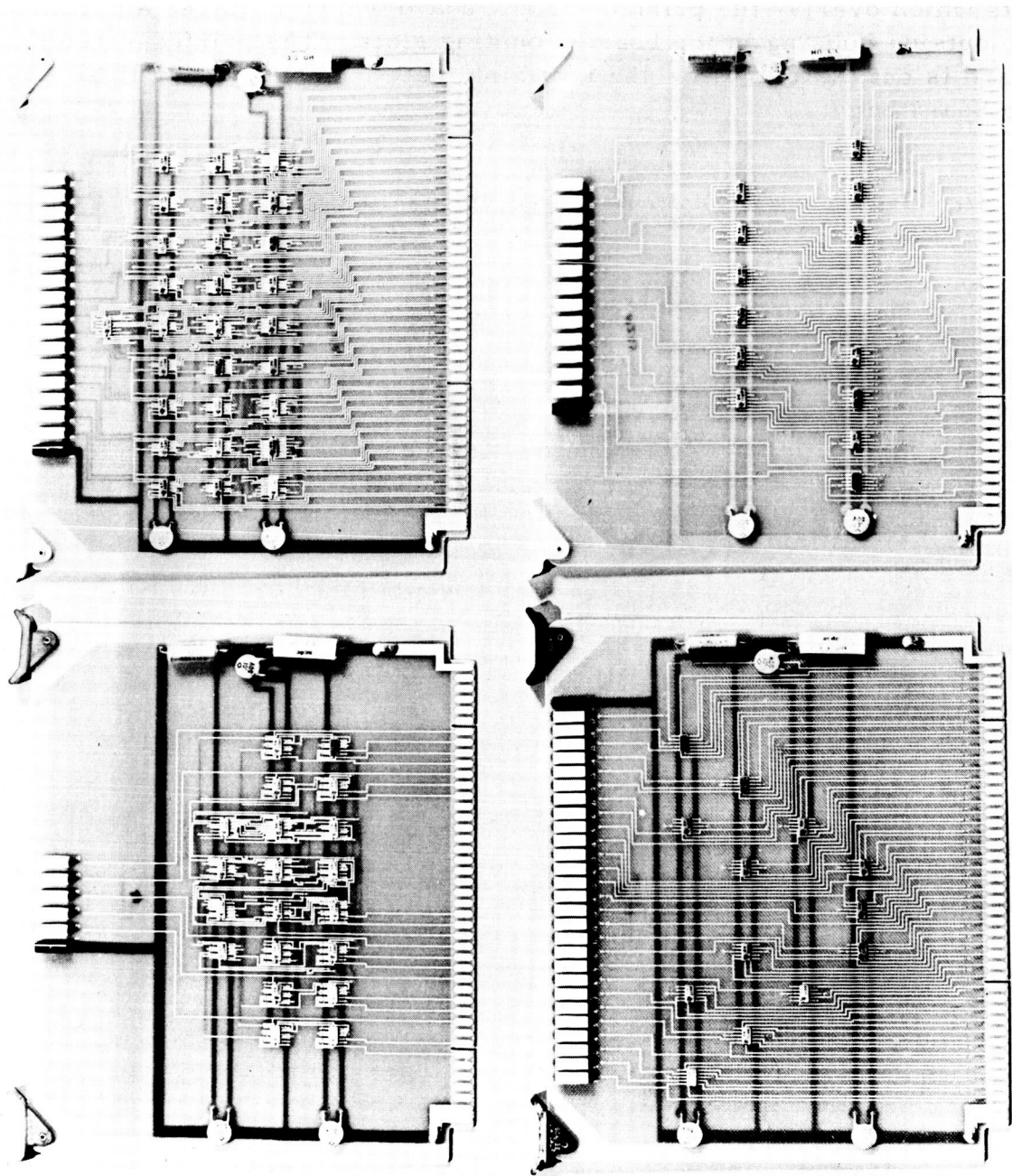


Figure 24. Low Density Printed-Circuit Boards

Multilayer boards are used in high density designs although their use was not favored in the past due to the apparent high cost. However, an in-house study showed that multilayer board designs were comparable to less dense designs in "cost/semiconductor network" at the system level.

b. Volumetric Efficiency

Within Texas Instruments' design concepts, volumetric efficiency is determined by the semiconductor-network density. The total package size determines the allowable volume for printed-circuit board occupancy, and the system design determines the total number of semiconductor networks that are needed. Combining such factors as these yields results in terms of the number of semiconductor networks per printed-circuit board, the conductor path width and spacing, the possible need for multilayer boards, the number of input and output pins to the system, etc. Two techniques of high density packaging were reviewed: the first was an assembly of 12 integrated-circuit flat packs stacked pancake fashion with mylar film separating the cases. The circuit interconnections were by vertical nickel ribbon welded to the quarter twisted flat-pack leads and terminated to output pins at the bottom, and the whole assembly was potted into a cubic module. In an airborne computer (Figure 25) which used approximately 50 of these modules, a metal plate was potted in at the top of each module. With the modules mounted side by side on a mother board, a large flat surface of metal module tops was arrayed. This composite surface contacted the lid of the outside package to provide a path for thermal conduction from the module to the package to the frame of the craft. Another example package using stacked integrated circuit flat packs is shown in Figure 26.

The second technique to high density packaging was the planar mounting of integrated-circuit flat packs to both sides of a miniature multilayer printed-circuit board. The density achieved with this method was 16 flat packs per  $1\frac{3}{4}$  by 2 inch board. These were assembled by parallel-gap soldering the flat pack leads to copper conductor patterns and conformal coating the finished board. An example of these double sided boards is shown in Figure 27.

The volumetric efficiency of an airborne computer package, using boards such as described, was enhanced at the next level of assembly by a board interleaving principle. Facing mother board pairs, with small daughter boards mounted normal to the mother board in every other available position, were brought together in final assembly so that the daughter boards meshed or interleaved much like a variable

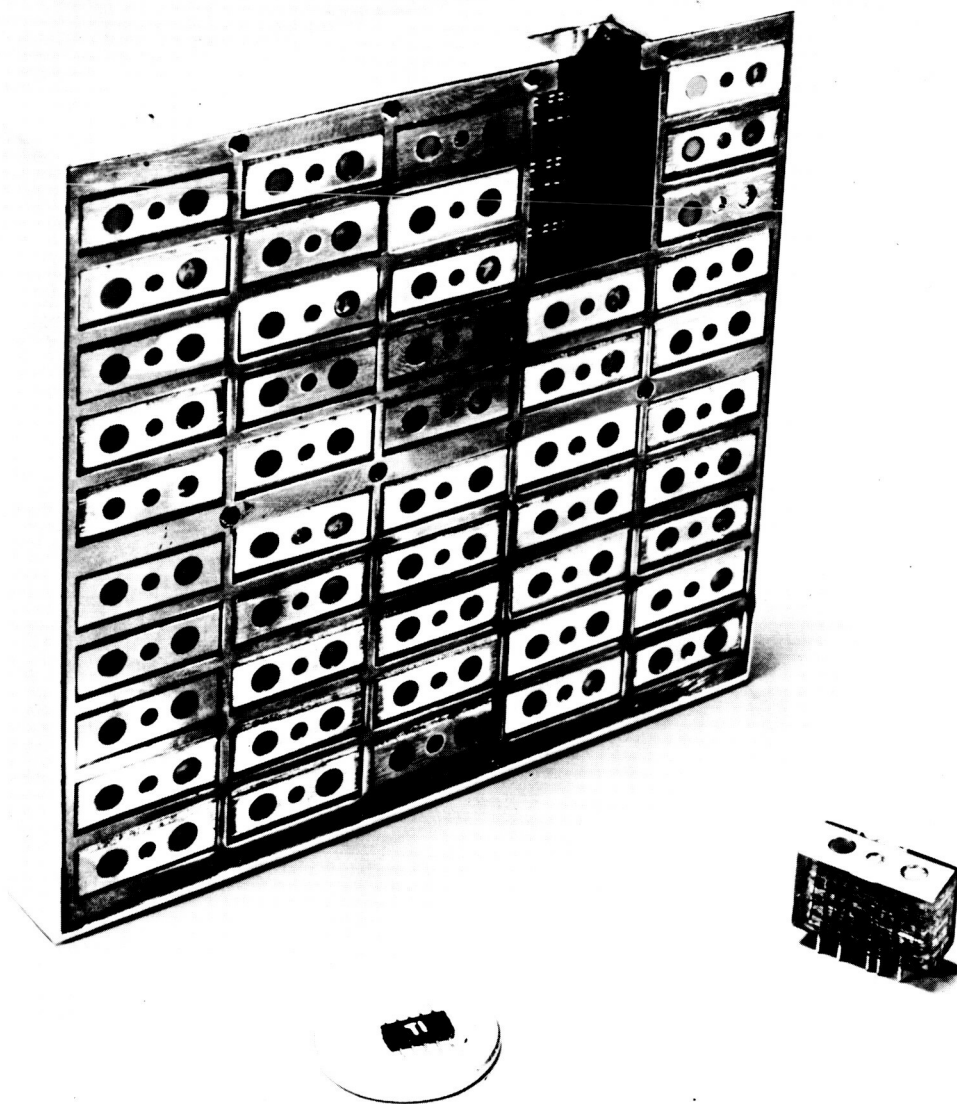


Figure 25. An Airborne Computer Uses 50 Modules of Stacked Flat Packs

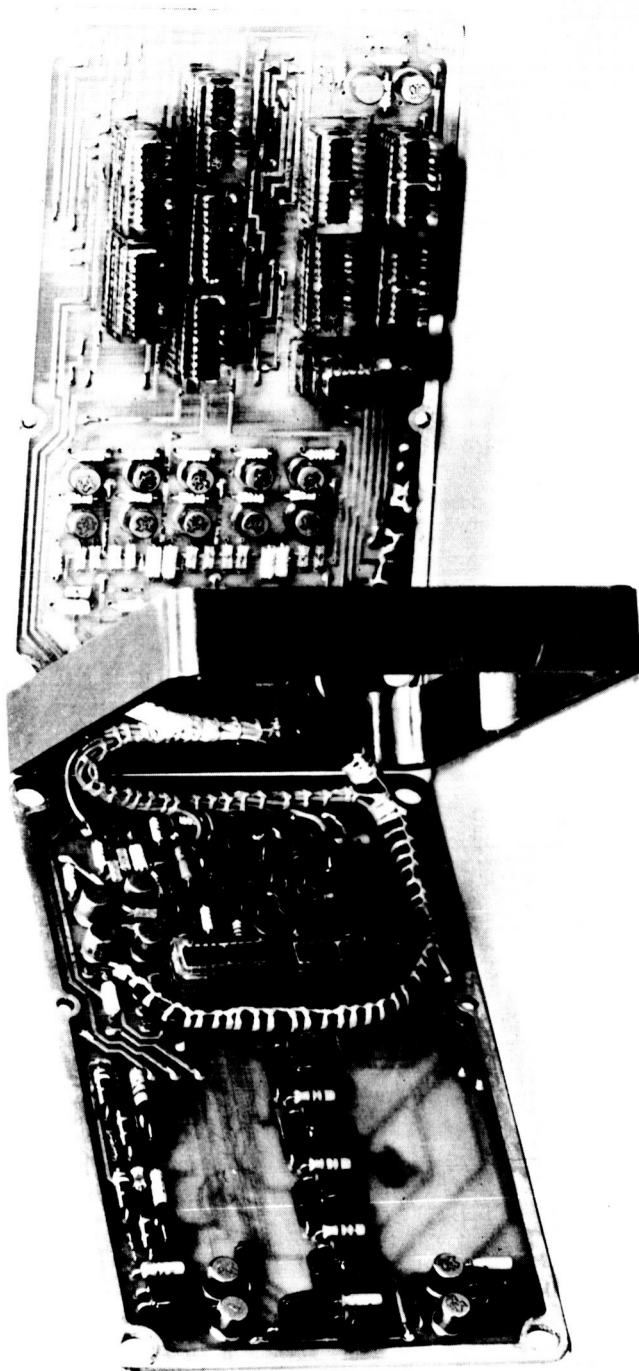


Figure 26. Digital Data Signal Conditioner

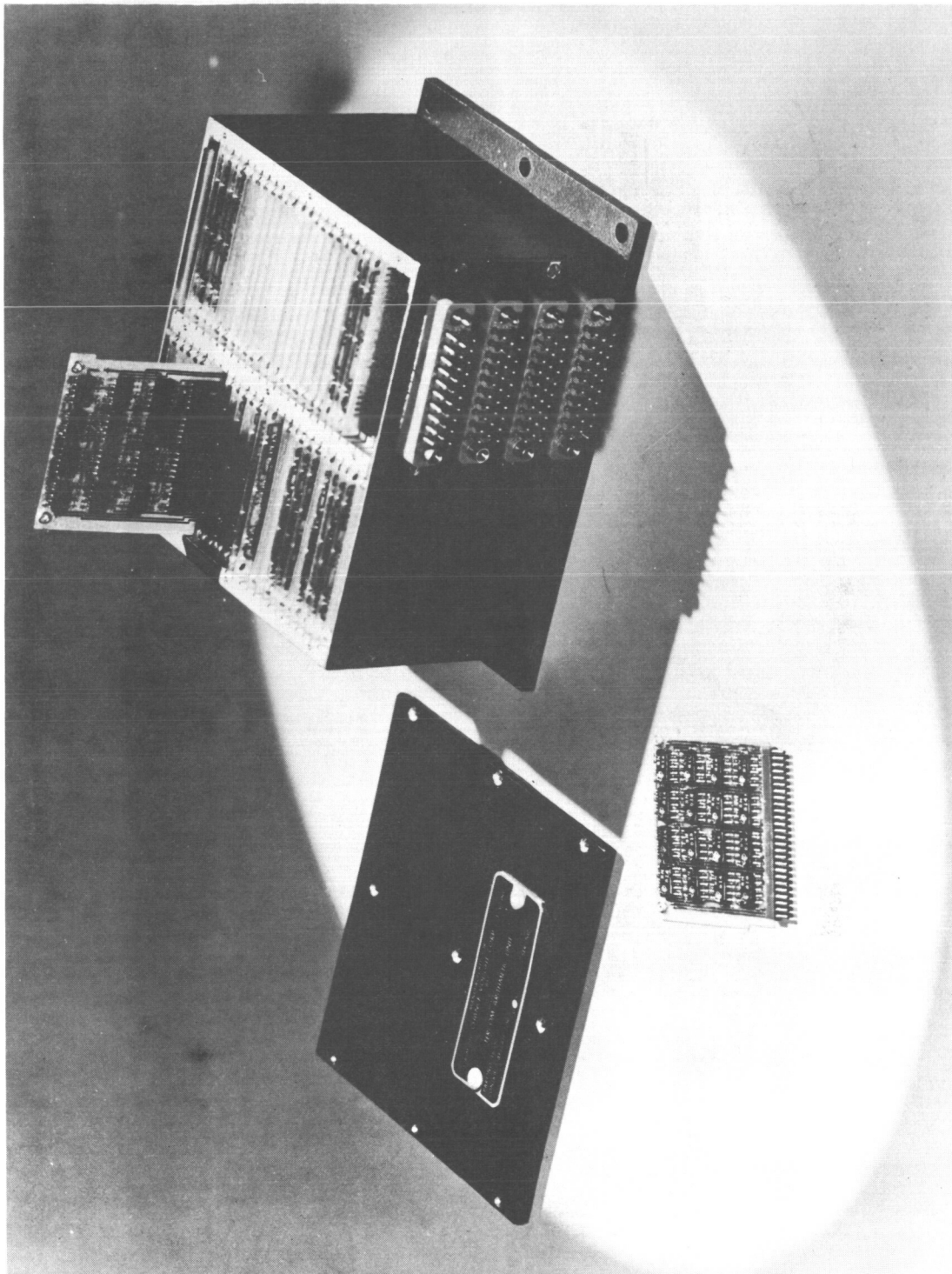


Figure 27. Integrated-Circuit Flat Packs Mounted to Both Sides of Multilayer Printed-Circuit Boards

air capacitor. This arrangement permitted a less complicated mother board design (11-layer boards were used) at very little increase in volume, and allowed a degree of access to the individual daughter boards for checkout and replacement which would not otherwise have been possible. A single assembly consisted of one hundred twenty 2 by 2.5 inch daughter boards which plugged into the mother board through Cannon Micropin connectors. Stability of the daughter boards was assured by their top edges fitting between the connector bases of the adjacent daughter boards on the opposed mother board half.

c. Miniature Connectors

Texas Instruments' selection of miniature connectors for their designs include such considerations as; allowable space for the connector, pin configuration, keying, and environmental criteria, i. e., effects of vibration, shock humidity, etc. In general, Texas Instruments favors the edge mount connectors and has standardized on 156, 100, and 50 mil pin center types. It is necessary to key the small integrated circuit planar boards both for placement of the various circuit functions on the mother board and for orientation of a given board in the connector socket. They have devised several schemes to accomplish this, one is a system of placeable tabs in the connector socket that engage mating slots in the etched-finger plug on the board edge. A large number of combinations is available.

d. Secondary Connections in the Integrated Circuit System

This broad subject which has been touched upon in several previous paragraphs includes multilayer board techniques, effects of potting, further considerations of connector types, mounting, and space requirements, and point-to-point wiring. The latter is an old "standby" method which is still used for limited production shipboard and ground-support equipment. Texas Instruments has adopted the AMP Termi-Point crimp connectors as a means of fastening the hard wiring to the connector-socket terminals. Texas Instruments likes the type of connection made, the ease of disconnecting and reconnecting wires when necessary, and the ability to connect three to four wires to the same terminal.

e. Enclosure Design Factors

In addition to such factors as application, space, weight, size, and environmental requirements in the design of enclosures, Texas Instruments considers maintainability of the circuit, mounting methods for the enclosure, appearance, and producibility. Their broad

scope requires everything from heavy sheet metal drawers with stamped in card guides for shipboard application to small, rugged, milled from solid block housings for aerospace devices. For medium production items with moderate vibration requirements (20 g, 200 Hz), Texas Instruments prefers the dip-brazed assembly method for production of housings because of inexpensive tooling. Where production exceeds quantities of 100, aluminum castings are used.

## Appendix B

### A SELECTED BIBLIOGRAPHY ON ELECTRONIC PACKAGING

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The following bibliography having 86 abstracts is in essence an addendum to a previous report entitled, "Electronic Packaging: A Bibliography," RSIC Report No. 534. The information in this bibliography includes more recent information obtained during the first six months of 1966 as well as a slightly expanded scope of open literature coverage.

This bibliography was defined as a very minor portion of the survey, so the coverage is incomplete (even for the time period cited). However, it provides a substantial addition to over 400 abstracts listed in the previous report.



## SELECTED BIBLIOGRAPHY

1. Allen, B. M. and Rubin, W.  
THE EFFECT OF MINOR CONSTITUENTS OF SOFT SOLDER,  
Industrial Electronics, November 1964, pp. 534-536.

A review is given of the effect of minor metallic constituents on tin-lead and similar alloys used as soft solder for electrical joints with reference to the possibility of modifying solders for special purposes by additions of such metals.

2. Amour, W. G., Klein, E. A., and Lenhart, D. D.  
ELECTRONIC PACKAGING IN THE PHOENIX MISSILE,  
IEEE Transactions on Parts, Materials, and Packaging,  
Vol. PMP-1, No. 1, June 1965, pp. s-237-s-247.

This paper contains a description of the concepts and techniques used in the electronic packaging of the Phoenix Missile Electronics Unit. The unit consists of etched circuit chassis pairs sandwiched between heat transfer panels. The sandwiches of heat transfer panels and chassis are compressed by end plates. Circuits such as logic networks, audio amplifiers, and high gain DC amplifiers are packaged in unique, welded, plug-in modules; circuits such as IF amplifiers and crystal-controlled oscillators are packaged in individual welded modules contained within aluminum investment castings. The other major features described are methods of providing thermal control and structural integrity.

3. Anderson, J. E., Dr. and Jackson, J. E.  
LASER WELDING--WHERE IT STANDS TODAY, Materials in Design Engineering, Vol. 61, No. 2, February 1965, pp. 92-96.

Laser welding can now be considered as a useful joining method, notably for electronic and other small assemblies. The high radiant power per unit cross-sectional area of lasers reduces the energy input required to produce a weld, thus reducing size of the heat affected zone. Since the heat source is a light beam, direct contact with the work-piece is not necessary. Also, welding can be performed through transparent materials, in any atmosphere, and without using electrodes. The optimum laser output required for welding

depends on the absorptivity, thermal conduction, density, heat capacity, melting point, and surface condition of the metals to be joined, as well as on the duration of the laser pulse. Joint strength, joint resistance, and processing data for a variety of metals and wire joint configurations are listed.

4. Author Unknown

PLASTIC FOAMS, Materials in Design Engineering, Vol. 63, No. 5, May 1966, pp. 87-102.

Plastic foams are cellular materials made by chemically or mechanically expanding resins. The foams consist of many cells which can either be closed or open. The cellular structure of the plastic provides good cushioning characteristics and very light weight. Depending on the resin that is foamed, they can be provided with a wide range of electrical properties and resistance to chemicals, weathering, and heat. Because of their unique properties, they can be used for thermal or acoustic insulation, flotation, filtration, electrical insulation, and packaging.

5. Author Unknown

RADICALLY NEW JOINING METHODS SIMPLIFYING AND IMPROVE PACKAGING OF MICROELECTRONIC CIRCUITS, Society of Automotive Engineers Journal, Vol. 73, No. 9, September 1965.

Recent radical advances in microelectronic circuits, especially the integrated and thin-film forms, are bringing equally radical advances in the methods used to join these microcircuits into more useful electronic systems. Many researchers have now turned to semiwelding or diffusion joining processes for connections used at the circuit level rather than the older fusion welding and soldering processes. The tiny assemblies produced by microelectronic techniques demand more protection than discrete component circuits, and improved methods of applying epoxy encapsulation are being developed. New packaging systems for microcircuitry are being evolved such as the flat-pack system, which is said to combine the best qualities of planar (2-dimensional) printed-circuit packaging and welded cordwood packaging.

6. Author Unknown  
RESISTANCE: FIRST CHOICE FOR WIDE RANGE OF  
MINIATURE JOINING, Welding Engineer, February 1965,  
pp. 42-46.

All resistance welding equipment consists of a head mechanism which is basically an electrode holder and a power supply. The electrodes are of major importance because they conduct the current to the workpiece and provide the necessary force for proper forging action. The ideal characteristics for an electrode are listed, and the proper electrode shapes for various applications are given. Several specialized techniques such as sandwich welding, series welding, and indirect welding have been developed for resistance welding of electrical/electronic parts.

7. Author Unknown  
RESISTANCE WELDING OF ELECTRONIC MODULES AT  
NASA'S GODDARD SPACE FLIGHT CENTER, Assembly Engineering, Vol. 8, No. 3, March 1965, pp. 20-22.

One of the important functions of the Goddard Space Flight Center is the layout and assembly of high reliability resistance welded modules. All component leads and interconnecting wires are mechanically and metallurgically analyzed for physical properties and composition prior to determining weld schedules. Equipment and procedures used for test production of the welded modules are discussed.

8. Author Unknown  
SHIELDING AND GROUNDING FOR INSTRUMENTATION  
SYSTEMS, Electromechanical Design, Vol. 10, No. 2,  
February 1966, pp. 52-57.

Basic considerations for the best shielding and ground practices in instrumentation are presented in the form of rules which give insight into the correct use and application of single-ended and differential amplifiers. These rules are then applied to multisignal systems with their complex grounding and ac power requirements.

9. Author Unknown  
ULTRASONIC WELDING, Machine Design, Vol. 36, No. 9,  
9 April 1964, pp. 130-132.

For certain applications, production techniques are in daily use for welding both aluminum/aluminum and aluminum/dissimilar metal welds. These techniques have been established by setting standards for welding-machine settings, surface preparation, joint-design factors, and special welding atmospheres.

10. Author Unknown  
VISUAL INSPECTION STANDARDS FOR PARALLEL-GAP  
SOLDERED JOINTS, Electronic Design News, March 1966,  
5 pp.

The many visual inspection standards presented are the results of a study that was made by using parallel-gap soldering techniques to connect integrated-circuit flat packs to etched circuit boards.

11. Bergan, M. D., Kaufmann, J., and Courter, R. C.  
SPICES, MULTISPICES, AND CLOSED-END CONNECTORS,  
Assembly Engineering, Vol. 7, No. 3, March 1964, pp. 40-43.

Solderless splices, or joints, between two or more wires can be made directly with several devices that have been developed specifically for this purpose. These devices, which eliminate the need for a terminal block as the intermediate wire connection point, include splices, multisplices, and closed-end connectors or pigtails.

12. Bergan, M. D., Kaufmann, J., and Courter, R. M.  
SPECIAL-PURPOSE CONNECTORS, Assembly Engineering,  
Vol. 7, No. 4, April 1964, pp. 32-37.

To meet the wide variety of electrical connection requirements encountered in product assembly, a large selection of special-purpose types of solderless connectors has been developed. This article examines the forms, features, and assembly requirements of some of the more common types of these devices; disconnect splices, terminals and connectors for shielded and coaxial cable, and high density wiring connections.

13. Browning, G. V. and Bester, M. H.  
EXPERIMENTAL EVALUATION OF RELIABLE SOLDERING  
PROCESS, Proceedings of the Ninth National Symposium on  
Reliability and Quality Control, 1963, pp. 211-221.

Laboratory tests to select optimum parameters for reliable soldering were conducted with emphasis on flux types, cleanliness, component lead and board material, soldering time and temperature, and mechanical factors. Conclusions emphasize the complexity of tests and control of variables needed to select optimum process parameters.

14. California Institute of Technology, Jet Propulsion Laboratory,  
Pasadena, California  
PACKAGING: THE BOTTLENECK OF MICROMINIATURIZA-  
TION by L. Katzin, Report No. NAS 7-100 (Unclassified  
Report).

Simplicity is the missing ingredient in today's microminiature packaging technology. As a result, the generation of microminiature hardware is dependent on inadequate human skills and nonapplicable design restrictions and manufacturing limitations to build short-run, highly reliable yet repairable hybrid systems, with a minimum of cost and lead time. There is obviously no panacea that will satisfy all requirements for all systems. However, automation is a method of optimizing tradeoffs for specific applications.

15. Chance Vought Corporation, Dallas, Texas  
EVALUATION OF PROTECTIVE ELECTRICAL COATINGS,  
Author Unknown, 15 March 1962, CVR Report No.  
2-53420/2R374, Fourth Quarterly Report, Contract No.  
AF 33(616)-7986 (Vol. 2, Phase I, Physical Properties of  
Some Engineering Materials - Unpublished Data From Company  
Sponsored Programs, 1 December 1961 - 28 February 1962,  
pp. 5-8) (Unclassified Report).

Electronic circuits function more reliably when protected from moisture, corrosion, fungus, and dirt. This protection may be obtained by coating electronic circuits with materials possessing suitable electrical and physical properties. Various protective materials have been screened at Chance Vought Corporation for use on terminal and printed circuit boards. Of the materials screened, PR 905 and Eccocoat VE appear to satisfy the majority of the desired properties. In addition,

a new product, PS 798 (previously XWC45041), appeared very promising in preliminary tests and is also evaluated.

16. Chance Vought Corporation, Dallas, Texas  
EVALUATION OF RIGID ELECTRICAL EMBEDMENT COM-  
POUNDS FOR USE FROM -55° TO 125°C, Author Unknown,  
15 March 1962, CVR Report No. 2-53420/2R374, Fourth  
Quarterly Report, Contract No. AF 33(616)-7986 (Vol. 2,  
Phase I, Physical Properties of Some Engineering Materials -  
Unpublished Data From Company Sponsored Programs,  
1 December 1961 - 28 February 1962, pp. 27-31)  
(Unclassified Report).

A rigid electronic embedment compound is required for use in computer modules. These modules are required to function at temperatures ranging from -55° to 125°C. Shell Epon 828 has excellent physical, electrical, and handling properties when catalyzed with Shell curing agent Z. Epon 828 resin catalyzed with curing agent D yielded equivalent electrical properties but slightly poorer physical properties, i. e., resistance to thermal shock, than the curing agent D yielded equivalent electrical properties but slightly poorer physical properties, i. e., resistance to thermal shock, than the curing agent Z, Epon 828 mix. In addition, the worklife of the curing agent D, Epon 828 mix had too little worklife for continuous or automated operation.

17. Change Vought Corporation, Dallas, Texas  
EVALUATION OF ELECTRONIC EMBEDMENT MATERIALS  
FOR USE AT 450°F, Author Unknown, 15 March 1962, CVR  
Report No. 2-53420/2R374, Fourth Quarterly Report,  
Contract No. AF 33(616)-7986 (Vol. 2, Phase I, Physical  
Properties of Some Engineering Materials - Unpublished Data  
From Company Sponsored Programs, 1 December 1961 -  
28 February 1962, pp. 32-40) (Unclassified Report).

Electronic modules embedded per standard procedure have not performed well during moisture environment qualification of certain electronic equipment. This condition necessitated the qualification of improved materials for this purpose. In addition, some growth potential with respect to temperature limitations is desired. Minnesota Mining and Manufacturing EC 1663 embedment compound has excellent electrical and physical properties for module embedment applications. The experimental compound, XD-911845, will require further

development by the manufacturer. The electrical properties of XD-911845 fell sharply as the temperature was increased.

18. Chance Vought Corporation, Dallas, Texas  
EVALUATION OF POTTING COMPOUNDS FOR 500°F APPLICATIONS, Author Unknown, 15 March 1962, CVR Report No. 2-53420/2R374, Fourth Quarterly Report, Contract No. AF 33(616)-7986 (Vol. 2, Phase I, Physical Properties of Some Engineering Materials - Unpublished Data From Company Sponsored Programs, 1 December 1961 - 28 February 1962, pp. 41-44) (Unclassified Report).

Increasing temperature requirements in aircraft and missiles have indicated a need for high temperature potting compounds. Dow Corning RTV 501 and Minnesota Mining and Manufacturing EC 1663 were the most satisfactory compounds tested. General Electric RTV 60 plus T-12 catalyst meets the physical and electrical requirements but has a short worklife and is difficult to mix properly. General Electric RTV 81813 was the prototype material to RTV-60 and had unsatisfactory high temperature properties. Proseal 792 also had poor high temperature characteristics.

19. Chance Vought Corporation, Dallas, Texas  
EVALUATION OF MATERIALS FOR USE AS ELECTRICAL ENCAPSULATION COMPOUNDS, Author Unknown, 15 March 1962, CVR Report No. 2-53420/2R374, Fourth Quarterly Report, Contract No. AF 33(616)-7986 (Vol. 2, Phase I, Physical Properties of Some Engineering Materials - Unpublished Data From Company Sponsored Programs, 1 December 1961 - 28 February 1962, pp. 49-52) (Unclassified Report).

The purpose of this test is to compare the properties of EC 1293 and Proseal 727 filled with quartz for use as an electrical encapsulation compound. EC 1293 meets all physical requirements. The only physical test that Proseal 727 plus quartz failed was working time. Proseal 727 passed every electrical test performed.

20. Cohen, N. I. and Sosoka, J. R.  
ELECTRONIC PACKAGING ENGINEERS DEVELOP NEW  
WAYS OF FASTENING FLAT-PACKS TO MOTHERBOARDS,  
Society of Automotive Engineers Journal, Vol. 74, No. 6,  
June 1966, pp. 53-58.

Two new ways of putting electronic systems together have been developed that provide increased flexibility and reliability at a reasonable cost. With the Sperry method, the conventional printed-circuit board is broken down into two levels as follows:

- 1) Small groups of the integrated-circuit modules are initially assembled onto the diminutive carrier boards.
- 2) Larger groups of carrier boards are mounted onto the motherboards.

The Weldmatic method uses an automated welder to weld the electrical connections between the flat-pack leads and the motherboard-circuit wiring. The combination of a moving welding head and moving carrier belt is used for the motherboard.

21. Davis, B. A.  
POTTING PROBLEMS RELATED TO PACKAGING DESIGN,  
Second International Electronic Circuit Packaging Symposium,  
Advances in Electronic Circuit Packaging, Vol. 2, pp. 77-89.

In a preliminary investigation of the phenomenon of fissure formation in a rigid epoxy-curing agent combination, it was found that nonuniform shrinkage of the cured mass is related to wetting effects of the liquid material prior to gelation. When wetting takes place, the material is prevented from maximum shrinkage during polymerization, such as occurs in cured mixes that do not wet a surface. The resultant is an overstressed area in the material which forms a fissure upon sudden applications of low temperature. Surface tension measurements indicate that the wetting effect of epoxy resin is increased when hardeners and fillers are added.

22. Disque, F. C., Jr.  
THE USE OF ROSIN AND ACTIVATED ROSIN FLUXES, 59th  
ASTM Symposium on Solder, 1956, pp. 64-70.

This paper reviews briefly the history of rosin base fluxes and points up the need for a better understanding of the



types available and their advantages. There is a controversy centering around the properties of the flux residue and its effect on the electrical circuit. With the increased use of printed wiring, the conductivity of the flux residue has become considerably more important than its corrosion potential.

23. Douglas Aircraft Company, Incorporated, Santa Monica, California  
STRESS ANALYSIS OF ENCAPSULATION MATERIALS FOR WELDED MODULES by M. H. Smith, February 1966, AD 628833 (Unclassified Report).

During the encapsulation process and subsequent thermal cycling, sensitive components and interconnections within welded modules are degraded by stresses induced in the filled epoxy materials. The epoxy encapsulation materials exhibited residual compressive stresses due to the initial cure of resin. Thermal cycling substantially increases these compressive stresses at the lowest temperatures. Tensile stresses were recorded during the elevated temperature phase of the test. Compressive stresses were produced as the cycle was completed forming a closed hysteresis loop, characteristic of these materials, on the stress versus temperature curve. Within a typical cordwood welded module with component density levels of 10 to 30 percent, the stress levels were reduced by increasing levels of component loading. The low density, microballoon-filled Sycast 1090/11 epoxy material exhibited significantly lower, more uniform tensile and compressive stresses than the medium-density, mineral-filled Hysol 4215/3561 (9709466, Type I) epoxy material within this same test configuration.

24. Economon, T. (Editor)  
RACK AND PANEL CONNECTORS, Electromechanical Design, Vol. 10, No. 3, pp. 50-58.

Design data and performance data are given for various connectors. These connector designs are not specifically covered by military specifications as denoted by manufacturer's data but have potential military and nonmilitary applications.

25. Electronic Defense Laboratories, Mountain View, California  
MULTILAYER BOARD APPLICATION TO RF CIRCUITRY  
by M. Hurowitz and W. E. Berg, 24 November 1965,  
EDL-M889, AD 629890, Contract No. DA 28-043 AMC-00379(E)  
(Unclassified Report).

Applications of miniaturization techniques to linear circuits in the very high and ultrahigh frequency ranges have been made successfully. The techniques of using extruded chassis with multiple layer printed circuit interconnection boards provide an additional method of producing microelectronic assemblies. The geometry enforces uniform packaging which allows for high systems-density. The form is compatible with both microelectronic elements and conventional components. The performance of microelectronic reactive components continues to be a problem. Even with the development of monolithic, linear, integrated circuits, the nonstandard nature of the equipment built by SES-W/EDL will require customizing of the response characteristics.

26. Emerson and Cuming, Incorporated, Canton, Massachusetts  
DEVELOPMENT OF INORGANIC FOAM MATERIAL OF  
CONTROLLED DIELECTRIC PROPERTIES FOR HIGH  
TEMPERATURE SERVICE, Author Unknown, 18 December  
1958, NOas 570357-c, Final Report, 5 November 1956 -  
15 December 1958 (Unclassified Report).

A low density, fine-grained structural material capable of withstanding 900°F has been developed by autogenous bonding of tiny glass bubbles. Emerson and Cuming, Incorporated, manufactures these bubbles under the trade name, "Eccospheres." Research on bonding techniques including silicone resin bonds as well as the autogenous bond is described. This structural material has been modified by additions of aluminum flake or titanium dioxide powder to give controlled dielectric constant structures having relatively low dielectric loss.

27. Flagg, W. and Lake, H.  
A SUCCESSFUL APPROACH TO VERTICAL STACK  
ASSEMBLIES OF FLAT PACKAGED MICROCIRCUITS,  
Electronic Components Conference, 1966, Washington, D. C.,  
pp. 280-284.

Spacecraft weight and volume allowances for the digital controls on the NASA ATS Program Despun Antenna demanded

modular volumetric efficiency that can only be achieved by stacking flatpacks. The need for efficient high density inter-connection of flatpacks with attendant high reliability requirements dictated development of new and novel approaches to interconnections. Since the system circuitry was still in the design stage, it was necessary to have a flexible technique so that circuitry changes would be accommodated without loss of a stack or its component parts. The development of inter-connection webs and ladders as described in this paper avoided the pitfalls and proved to be the way to a successful vertical stacked assembly of flat packaged microcircuits.

28. Foster, F. G.  
EMBRITTEMENT OF SOLDER BY GOLD FROM PLATED SURFACE, 65th ASTM Symposium on Solder, 1962, pp. 13-19.

Poor joints are often encountered while soldering gold-plated parts. Although the solder wets the parts, roughness, porosity, and brittleness may be present. This is particularly true where the gold plate is heavy and the amount of solder is small. Microscopic study shows the presence of long, hard, white crystals in the solder of such joints. The effects of various concentrations of gold in 60-40 tin-lead solder and in tin and lead are reported.

29. Fulton, D.  
A NUMERICAL RATING SYSTEM FOR CHOOSING ELECTRICAL CONNECTIONS, Machine Design, Vol. 26, No. 18, 30 July 1964, pp. 102-107.

The system described here is the first major attempt to assign numerical values, weighted by application, to connection selection factors. Comparative cost per joint and performance under various environmental conditions are not considered. The merit index derives a single number representing the desirability of using a particular connection method solely from operating experience. This index number is the sum of as many selection factors as are pertinent to the decision; the higher the number, the more desirable the connection. Although more factors could be considered, practical experience dictates inclusion of at least 10; joint life, connection density, compatibility, preparation, mass producibility, process control required, inspectability, repair time, repair skill, and maintenance tools needed.

30. Gallacher, L. V.  
HEAT SINKS AND ENCAPSULANTS FOR VOLUMETRIC  
PACKAGING, Advances in Electronic Circuit Packaging,  
Second International Electronic Circuit Packaging Symposium,  
Boulder, Colorado, Vol. 2, 76 pp.

Attendant with the high volumetric efficiency achieved in three-dimension modular packaging is high heat dissipation per unit volume. Unfilled epoxy resins are poor heat conductors, so that it appears unlikely that epoxy resin encapsulants can dissipate much heat from operating components. As a result of this study, several conclusions may be drawn as follows:

- 1) Substantial improvements in heat dissipation and thermal conductivity in epoxy resins are achieved by incorporating certain fillers and metallic conductors into the resins.
- 2) Encapsulants can be made to act as efficient heat-transfer media despite their relatively low thermal-conductivity coefficients.
- 3) The incorporation of aluminum honeycomb and heat exchangers in resins results in greatly increased heat-transfer rates.
- 4) Mounting of modules on cold plates results in substantial improvements in heat transfer over still air.
- 5) The use of blowers effectively increases the heat dissipation rates of modules, depending upon the surface temperature.

31. Garibotti, D. J. and Ullery, L. R., Jr.  
PRODUCTION-LINE PACKAGING OF SOLID-STATE CIRCUITS,  
Fundamentals of Modern Electronics Engineering, Vol. 1,  
pp. 237-243.

An automated assembly procedure for microcircuit modules is described in which the production line includes an electron-beam welding machine that performs final assembly and hermetic sealing of the modules. When electron-beam welding is used, the circuits are sealed in a vacuum. Individual packages for the components would be superfluous. This saves the cost of having components prepackaged and allows shorter lead lengths for better high-frequency performance. Other production and performance advantages are built into the microcircuit module. No fluxes or encapsulants are

necessary; contaminants are minimized, and stresses associated with potting are avoided.

32. Gellert, R.

UPDATING PRINCIPLES AND CAPABILITIES OF ULTRASONIC JOINING, Machine Design, Vol. 37, No. 30, March 1966, pp. 136-140.

There are two distinct methods of using ultrasonic energy in metal joining. One method is to apply ultrasonic energy to metals being soldered, brazed, or welded. This aids the joining process, although heat is still needed to bring the filler metal or base metal to its melting temperature. This might be called ultrasonically-assisted fusion welding, soldering, or brazing. Metals can also be joined by clamping them together and applying the ultrasonic energy in the plane of the weld without the application of heat. This is called ultrasonic welding and is a solid-state bonding process since the metals being joined never reach melting temperatures. Ultrasonic welding joins such configurations as 300-microinch diameter wires, 170-microinch thick foils, thin wires or foils to heavier sections, aluminum to metallized glass, and gold and aluminum leads directly to silicon or germanium. In the area of encapsulation, ultrasonic ring welders are being used to package everything from transistors to volatile or explosive materials. Chemicals can be hermetically sealed without fear of contamination by fluxes, molten materials, or epoxies. Structural members as well as small wires and foils can be joined by ultrasonic welding. It has been determined that the amount of ultrasonic energy required to bring a metal into a given plastically deformable state is far less than the amount of heat energy necessary to produce the same state.

33. Gerhold, R. A. and Elders, D. S.

EFFECTIVE PACKAGING OF MICROELECTRONICS WITH MICROMODULES, Seventh National Convention on Military Electronics, New York, Institute of Electrical and Electronics Engineers, 1963, pp. 357-360.

The enhanced micromodule provides a highly efficient, reliable, low cost approach for incorporating advanced integrated circuits into military equipment. At the same time, it retains the advantages of compatibility, at either the micro-element or module level, with the broad range of high-performance capability already established under the

Micromodule Program. The standard micromodule is a stack of 10 microelements (wafers), each 0.31 in.<sup>2</sup>, with 12 (three per side) riser conductors; the whole hermetically encapsulated. The wafers are obtained from various manufacturers and can be discrete modular, thin film or semiconductor integrated circuits, or hybrid. An "enhanced micromodule" has 36 (nine per side) electron beam welded riser conductors. Three hundred different circuits have been constructed in micromodule form and tested.

34. Gerstin, H.  
HOW TO EVALUATE THE RIGID PLASTIC FOAMS, Product Engineering, Vol. 36, No. 13, 21 June 1965, pp. 59-68.

The major types of plastic foams in use today are expanded polystyrene, urethane, epoxy foams, silicone foams, phenolic foams, and syntactic foams. To facilitate production or improve the quality of the foam, various additives may be mixed with the basic resin - catalysts, surfactants, extenders, fire retardants, coloring agents, and metal powders. The physical properties of the various types of foams are tabulated, and their resistance to chemicals, flame, vibration, high temperatures, water absorption, and fungus attack is discussed.

35. Gibson, A. M.  
CERTIFICATION. A LOGICAL APPROACH TO RELIABLE MODULE WELDING, Eighth Symposium of the Welded Electronic Packaging Association, Syracuse, New York, 21 June 1963, 19 pp.

This report delves into the aspects of product reliability, which are solely dependent upon fabrication efficiency. Major variables in considered order of influence upon successful module welding are:

- 1) Dependability of electrical and mechanical equipment.
- 2) Authenticity of welding specifications.
- 3) Measure of competence of welding operators.

36. Griffin, D. C.  
HERMETIC PACKAGING FOR SEMICONDUCTOR DEVICES,  
SCP and Solid State Technology, Vol. 8, May 1965, pp. 42-45.

A review is given of glass- and ceramic-metal seals including techniques employed in the manufacture of seals. Broad and commonly accepted classification of seals in two categories of matched and unmatched seals is discussed. Advantages and disadvantages of ceramic-metal seals are compared to glass-metal seals.

37. Hauck, J. E.  
A GUIDE TO PLASTIC FILMS AS ENGINEERING MATERIALS,  
Materials in Design Engineering, Vol. 62, No. 4, October  
1965, pp. 102-107.

A table of mechanical, physical, electrical, and chemical properties of many common plastic films materials is presented. Many applications of these films are discussed, including their use in printed circuits.

38. Hauck, J. E.  
TRANSFER MOLDED EPOXIES UPGRADE ELECTRONIC  
PARTS, Materials in Design Engineering, Vol. 63, No. 3,  
March 1966, pp. 76-79.

Recent improvements in the properties and processing characteristics of epoxy transfer molding compounds have resulted in growing use of the materials for encapsulating electronic parts. Compared to competitive materials, the epoxy transfer molding compounds provide a better balance of properties and are easier to process. The epoxy compounds can be molded at rapid production rates at low cost with a high degree of reliability. Also, they can be used to package a wide range of delicate and temperature sensitive assemblies, such as integrated circuits, semiconductors, and glass substrates and components.

39. Heberlein, M. F. W.  
EFFECT OF IMPURITIES ON SOME PROPERTIES OF LEAD-  
TIN ALLOYS, 65th ASTM Symposium on Solder, 1962,  
pp. 29-38.

A research investigation on the effects of the common impurities on the soldering properties of various lead-tin

alloys is described in detail. Observations of these effects after carefully measured additions of antimony, arsenic, bismuth, silver, copper, phosphorus, and sulfur are compiled and discussed. Reliable conclusions can be drawn about the quality of a solder by hot-dipping steel, brass, or copper into a molten pool of such an alloy. The tolerable limits of impurities in an all-purpose solder were determined to be as follows:

- 1) Antimony - 0.4 percent.
- 2) Arsenic - 0.02 percent.
- 3) Copper - 0.06 percent.
- 4) Phosphorus and sulfur - as low as possible, preferably nil.

40. Heightley, J. D. and Mallery, P.  
EXPLORATORY STUDY OF BONDING METHODS FOR LEADS  
ON 2.5 TO 50 MIL. CENTERS, Electronic Components  
Conference, 1966, Washington, D. C., pp. 168-177.

The decreasing size of components places new demands on bonding techniques. Bonding 0.001 leads with 0.0015 spacing to substrates is one present requirement. This paper presents the results of an investigation comparing the advantages of parallel-gap welding, impulse soldering, ultrasonic bonding, and two types of thermocompression bonding for bonding leads to substrates. The maximum spacing considered is 0.050 centers with emphasis on bonding gold beam leads on centers down to 0.0025, the spacing used on an integrated 32 transistor package.

41. Heitert, D. G.  
A WELDING PROCESS DEVELOPED FOR PRODUCTION,  
Eighth Symposium of the Welded Electronic Packaging Association, Syracuse, New York, 20 June 1963, 15 pp.

This paper is a comprehensive disclosure of the planar welded module process for modular electronics design, tooling, and production. The planar terminology is derived from the two-dimensional weldment configuration intrinsic in the concept, in contrast to the three-dimensional cordwood modules. Features of this new development include improved performance characteristics and greatly improved producibility. Among those outlined are:



- 1) Increased reliability through an effective quality assurance program.
- 2) Higher production rates and reduced costs through precise tooling.
- 3) Reduction of human error factors.
- 4) Lack of dependence upon weld station operator skills.

42. Hogrefe, A. F.

DESIGN AND PACKAGING OF ELECTRONICS TO SURVIVE AN EXTENDED MISSION IN THE NATURAL AND ARTIFICIALLY TRAPPED BELTS OF NEAR SPACE, National Electronics Packaging Conference, 1964, 18 pp.

Microcircuitry is of interest to the designer of spacecraft, and, accordingly, an investigation was made of radiation effects on eight silicon monolithic integrated circuits, as well as on other electronic devices. The amount of available information on the radiation susceptibility of various components is small and many applications will require extensive testing to guarantee a good degree of reliability. Alternately, the designer may choose to ameliorate the environment by appropriate shielding.

43. Hughes Aircraft Company, Solid State Research Center, Newport Beach, California

THIN FILM MICROCIRCUIT INTERCONNECTIONS, Author Unknown, October 1965, Final Report, AD 628225, Contract No. DA28-043 AMC-00052(E) (Unclassified Report).

A program study of deposited thin film interfacial connections and electrical crossovers has been completed. Test patterns have been designed which permit the study of the interconnection and the crossover with minimal intrusion from contacts and film properties. Design criteria have been established for the material combinations which are compatible for the purposes of the thin film interconnections and crossovers. The accuracy of these criteria to perform the task of forecasting the ability of any interconnection or crossover to function in military environments was verified statistically. As a result of the program, all the material combinations are placed in forced rank according to their relative merits. The reasons for each choice are given.

44. Isaacson, H. M.  
DIP SOLDERING IN MINIATURE - A NEW WAY TO ASSEMBLE  
MODULES, Electronics, Vol. 39, 31 May 1965, pp. 94-96.

As the size of electronic modules shrinks, the problem of protecting components from thermal damage during assembly becomes greater. Hand soldering can damage heat-sensitive components in microminiature assemblies because the bodies of the components are placed so close to the solder joints. Such thermal shock can be avoided by a new method of hand soldering which reverses the usual procedure. The joint between the component lead and the connecting wire is dipped into a small globule of melted solder instead of the lead being heated until it melts the flux and solder. In this way, the joint is heated only to the temperature of the molten solder, not higher. The new technique is particularly useful in the assembly of cordwood modules.

45. Jackson, J. E.  
PACKAGING WITH LASER WELDING, SCP and Solid State Technology, Vol. 9, No. 5, May 1966, pp. 21-28.

The laser has been shown to be capable of producing fusion welds on circuit boards without damage to the substrate. The board claddings tested include copper, nickel, kovar, and multilayer variety. Advanced electronic packaging will be aided by the unique features of laser welding. The number of suitable uses for laser continues to increase. Because laser welding is limited to pulsed devices (for the near future), it will be used on microassemblies only. There are a few guidelines that can be used to determine when laser welding should be considered. In its present state of development, an upper limit to the depth of the required weld bead should be about one-thirty-seconds of an inch. Most applications will probably involve welding pieces at thicknesses below 0.020 inch. In addition, the application should take advantage of at least one of the unique features of the laser. For emphasis, they are summarized as follows:

- 1) Low heat input.
- 2) Welds difficult metals.
- 3) No metal contact with weld.
- 4) Microminiature fusion.

46. Johns, A. A., Jr. and Miller, E. S.  
DIP-SOLDERED PRINTED CIRCUIT JOINT CHARACTERISTICS,  
59th ASTM Symposium on Solder, 1956, pp. 115-128.

Considerable emphasis has been placed upon a program of investigation of dip-soldered joints from the standpoint of results which can be anticipated in production. This program covers the following fields of information on dip-soldered joints:

- 1) Efficiency of joint formation.
- 2) Short-time tensile strength.
- 3) Impact strength in tension.
- 4) Creep strength in tension.

The possibility of strengthening dip-soldered joints was also investigated.

47. Kamensky, A.  
PERFORMANCE AND RELIABILITY OF PLATED MULTILAYER  
PRINTED WIRING JOINTS, Electronic Components Conference,  
1966, Washington, D. C., pp. 178-190.

Plated through-hole multilayer epoxy-glass printed wiring board joints were evaluated for their performance limits and reliability under severe simulated aerospace environmental conditions. The data indicate that environmental test extremes had far less effect on plated joint reliability than fabrication process variables. Continuity tests were found to be of little value as a true measure of quality, but microsection (metallurgical) evaluation was confirmed as a valid measure of quality when used in conjunction with joint resistance. The plated multilayer joint was proven to be a sound design capable of withstanding environmental extremes in excess of those presently foreseen for aerospace applications. This work is intended to illustrate a method for determining through-hole plated joint reliability.

48. Katz, I.  
NEW MATERIALS FOR OLD, Electromechanical Design, Vol. 10,  
No. 3, March 1966, pp. 27-28.

The properties of vulcanized fiber, resin-impregnated vulcanized fiber, laminated fibers, and resin impregnated glass filaments are described in relation to their structural, insulation, and electromechanical design functions.

49. Katz, I.  
STATUS OF THE FILLED COMPOSITES, Electromechanical Design, Vol. 10, No. 2, February 1966, pp. 18-21.

A quick assessment of the current and potential merits of the filled composites is given. One major area for the application of filled plastics is the production of circuit boards in which the composite forms a substrate for printed circuit elements and contains a combination of multilayer metals. The metallic layers may be etched, machined, or otherwise processed into conductors to which you can attach circuit components by vacuum deposition, plating, printing, welding, soldering, or mechanical fastenings. In such arrangements, the filled substrate provides an insulation function, although a stiff metal member in the multilayer metal section could provide strength in addition to a thermal barrier for welding and soldering operations.

50. Keller, J. D.  
PRINTED WIRING SURFACE PREPARATION METHODS - ELIMINATION OF GOLD PLATING AS A SURFACE PREPARATION FOR PRINTED CIRCUITS AND DEVELOPMENT OF A CONTAMINATION-FREE SURFACE, 65th ASTM Symposium on Solder, 1962, pp. 3-12.

The research objective was to eliminate printed circuit gold plating and to develop a method for chemically cleaning surfaces guaranteeing high solderability at low costs. Copper surfaces were found to be more advantageous than gold for this soldering application. A procedure for cleaning and coating copper surfaces is described.

51. Kelley, F. E.  
A PRACTICAL ANALYSIS OF OVERPRESSURE CONTROL, Eighth Symposium of Welded Electronic Packaging Association, Syracuse, New York, 20 June 1963, 15 pp.

A comprehensive weld evaluation program was conducted to determine conclusively the effect overpressure has on weld quality. The statistically analyzed test results demonstrated overpressure to be desirable. Although average tensile strength remained virtually unchanged, the range of tensile strengths was reduced 50 percent by deliberate overpressure. Weld pressure and watt-second combinations have been surveyed. From these tests, it has been shown that a mere increase in

welding pressure does not produce the same effects as over-pressure which introduces a different pressure - time history. Therefore, welding heads incorporating a forge cycle appear to be desirable to attain high quality weld joints.

52. King, J.  
RESISTANCE, TIG, OR ELECTRON BEAM WHICH WAY TO WELD? Product Engineering, Vol. 35, No. 21, 12 October 1964, pp. 77-83.

The electron beam provides a deep, narrow weld for a range of applications from microcircuitry to heavy plate. Resistance welding is best suited to high production of lap welds where the material is thin. The process can also be used for high-production flash butt welding of small sections such as bar stock, extrusions, or sheet material. TIG (tungsten inert gas) welding is a relatively low-production process for making shallow-penetration multiple-pass welds of fillet, butt, and limited thickness lap joints wherever weld purity is important. All three welding processes create a molten area which coalesces across the joint. They differ in the diameter of this molten area and in extent of the heat-affected zone. TIG welding produces the largest molten area and, because it is a slow process, also produces the largest heat-affected zone. Resistance welding produces a smaller molten area and a very small heat-affected zone. Welding time is very short. The smallest molten area, down to 0.005 inch wide, is produced by the electron beam which can be focused to a fine point, creating heat almost instantaneously only in the path of the beam.

53. Kutzer, L. G.  
JOINING CERAMICS AND GLASS TO METALS, Materials in Design Engineering, Vol. 61, No. 1, January 1965, pp. 106-110.

The various methods and materials for joining a ceramic or glass material to metal can be divided into three general categories:

- 1) Mechanical fastening.
- 2) Cements, adhesives, and low melting alloys.
- 3) Fusion bonding.

Mechanical fastening is used primarily where a perfect seal is not required between the ceramic or glass and the metal.

The principal methods and devices that can be used are shackle pins and cables, threaded joints, and press and shrink fitting. Also, it is possible to combine these methods and devices with cements, adhesives, and low melting alloys to obtain a more effective seal. Fusion bonding provides an intimate joining of the ceramic or glass with the base metal. It is used to provide a hermetic seal with little leakage.

54. Lander, H. J.  
ELECTRON BEAM: SUITABLE FOR JOINING EVEN ULTRA-  
SMALL PARTS, Welding Engineer, February 1965, pp. 55-57.

Electron beam welding is particularly suited for joining small parts. Its main limitations are:

- 1) The electron gun must be operated in high vacuum.
- 2) Materials must be handled in vacuum.
- 3) The initial cost of the equipment is high. However, this technique has advantages over other welding techniques, and these advantages are discussed from the points of view of the metallurgist, design engineer, and welding engineer.

55. Lane, W. V.  
WELDED CONNECTIONS, Machine Design, Vol. 36, No. 12,  
21 May 1964, pp. 209-214.

Welded interconnection of discrete-part modules utilizes almost exclusively resistance-welding techniques, primarily resistance spot welding. Rapid advances in microelectronics are precipitating a new era of electronic fabrication involving many new welding techniques such as thermocompression bonding, ultrasonic welding, series resistance welding, and laser and electron-beam welding. An important area in electronic-circuit packaging interconnections is backplane wiring involving closely spaced terminals which must be interconnected by a suitable wiring harness. Common connections used for this kind of application are crimp removable contacts, taper pins, wrapped connections, and percussive-arc welding. Thermocompression bonding, series welding, and ultrasonic welding are primarily used in microelectronics for intra-connection of thin-film and solid-state devices on a single substrate.

56. Larson, C. D.  
EMBEDMENT OF ELECTRONIC MODULES BY TRANSFER  
MOLDING, IEEE Transactions on Parts, Materials, and  
Packaging, Vol. PMP-1, No. 1, June 1965, pp. s-169-s-177.

One of the latest and most interesting techniques in the use of plastics for electronic packaging is the total embedment of an assembled circuit in a closed mold utilizing a transfer molding press. This technique uses a combination of heat and pressure to liquefy a powdered or granular plastic compound in a transfer pot, and subsequent introduction of the plastic into the mold cavity while maintaining a carefully controlled heat and pressure on the transfer plunger. In comparison with the more recognized techniques of potting or encapsulating with liquid plastic systems, this new technique yields a better appearing product at a lower cost.

57. Mample, A. Z.  
SOLDERING FLUXES AND FLUX PRINCIPLES, 59th ASTM  
Symposium on Solder, 1956, pp. 71-80.

Successful soldering is an art that requires consideration and evaluation of the solder metal, flux, temperature, quantity of heat and method of application, type and condition of surfaces involved, and the use to which the item will be put. An evaluation of a flux should include consideration of its corrosion and conductivity.

58. Manko, H. H.  
CHOOSING THE RIGHT SOLDER ALLOY, Electronic Industries,  
Vol. 24, No. 3, March 1965, pp. 102-105.

The following check list provides the parameters to be considered in making a solder alloy selection, based on the assumption that base-metal selection is determined by the mechanical and electrical properties required:

- 1) Flux selection.
- 2) Temperature considerations.
- 3) Freezing range.
- 4) Mechanical properties.
- 5) Electrical properties.
- 6) Special characteristics.
- 7) Economy.
- 8) Compatibility checks.
- 9) Manufacture suitability.

59. Manko, H. H.  
MECHANISM OF WETTING DURING SOLDER JOINT FORMATION, 65th ASTM Symposium on Solder, 1962, pp. 20-28.

The mechanism involved in the formation of the solder bond and the source of its strength is described. The soldering of two metals requires the establishment of an interface where the solder is bonded to each of the two metals, thus giving the desired metallic continuity in the solder joint. The formation of the interface in a solder joint requires the following elements:

- 1) The solder alloy itself.
- 2) The base metal.
- 3) The flux or atmosphere in which the process takes place.

The thermodynamic equilibrium between the surface energies and the use of the dihedral angle in the evaluation of wetting conditions are described. The sequence of events leading to the solder joint formation is shown and an indication given of how the wetting information can be translated into a practical quality control system.

60. Manko, H. H.  
SOLDERED CONNECTIONS, Machine Design, Vol. 36, No. 12, 21 May 1964, pp. 190-195.

The following soldered joint characteristics are discussed:

- 1) Physical properties.
- 2) Electrical properties.
- 3) Thermal properties.
- 4) Corrosion resistance.

To adequately design an assembly for reliable and economical soldering, the following phases need careful consideration:

- 1) Materials selection.
- 2) Geometrical design.
- 3) Process parameters.
- 4) Inspection and control.



61. McQuillan, W. P.  
GUIDE TO SOLDERING, Welding Engineer, April 1965,  
pp. 64-67 and 112-115.

The topics considered in this article are:

- 1) Principles of good soldering.
- 2) Solder alloys in use today.
- 3) The effects of various fluxes.
- 4) Criteria for selecting solder and flux.
- 5) The available soldering methods and equipment.

62. Meyer, F. R.  
ULTRASONIC WELDING, ITS PRINCIPLES, REQUIREMENTS,  
AND USES, Assembly Engineering, Vol. 9, No. 3, March 1966,  
pp. 20-26.

In many instances, this process makes better-quality joints, reduces joining costs, and speeds production processing. Typical uses are found in joining electrical and electronic components, hermetic sealing of materials or sensitive devices, fabricating nuclear fuel elements, splicing thin metallic foils, and welding aluminum. High-strength metallurgical bonds can be made in many similar and dissimilar metal combinations without applying external heat, without melting weld metal, without using fluxes or filler metal, and without passing electrical current through the joint. Thickness deformation is negligible. Joining capability is limited essentially only by the power capacity of available equipment.

63. Miller, E. S. and Johns, A. A., Jr.  
DIP SOLDERING PRINTED CIRCUITS, 59th ASTM Symposium  
on Solder, 1956, pp. 30-40.

Economical, reliable joints can be made using dip soldering, provided certain precautions are taken. Consideration is given to means of eliminating potential problems in the dip soldering process.

64. Molzon, A. M.  
RECENT DEVELOPMENTS IN CASTING RESINS AND TECHNOLOGY FOR ELECTRICAL ENCAPSULATION APPLICATIONS,  
31 pp.

Recent developments in plastic casting resins, processing techniques, and test methods for electrical encapsulation

applications are summarized. Polymeric casting materials used today include epoxy, polyester, polysulfide, silicon, polyurethane, and hydrocarbon. Epoxy-based formulations are the most widely used materials, and with polyester resins, they constitute the rigid-type material. Silicones cost more than the other materials, but they have better temperature capabilities (high, low, and extended range). Polysulfides and polyurethanes have found their largest use in sealing-type applications (cables, connectors) and it appears that the polyurethanes will increase in popularity at the expense of other materials because of their combination of properties such as toughness, thermal shock resistance, flexibility, and cold-flow resistance. The development of expendable molds, plastic cartridges, and premeasured kit-type packaging has facilitated the use of encapsulating materials.

65. Moore, D. W.

INTERCONNECTIONS AND PACKAGING - THE MOST CRITICAL AREAS OF MICROCIRCUIT APPLICATION, Electronic Components Conference, 1966, Washington, D. C., pp. 144-148.

Soldering, welding, and wire-wrap are all satisfactory methods for forming highly reliable interconnections. Plug-in connectors are not always highly reliable. Interconnections and packaging are now the most expensive portions of any large microcircuitized system, and those interconnections which are required must be highly reliable so that the reliability inherent in integrated circuit functions is not seriously degraded.

66. Morgan, H. S.

PHOTOETCHING PRODUCES THIN, CLOSE TOLERANCE METAL PARTS, Materials in Design Engineering, Vol. 61, No. 3, March 1965, pp. 124-126.

Small precision parts can be formed with extreme accuracy by photoetching. The process can be used with a wide variety of ferrous, nonferrous, and composite metals less than 20 mils thick. It can accommodate parts up to 20 inches square and will produce holes or slots in sizes down to the thickness of the metal itself. The fine etching action of the process produces parts free of burrs, internal stresses, and distortion. In addition, their physical and mechanical properties are unaffected, and high dimensional accuracy and uniformity are assured.

67. Mueller, R. J.  
NEW ELECTRICAL CONNECTOR SPECIFICATION ANSWERS  
SPACE-AGE ENVIRONMENTAL NEEDS, IEEE Transactions  
on Parts, Materials, and Packaging, Vol. PMP-1, No. 1,  
June 1965, pp. 248-256.

The new specification for electrical connectors MIL-C-38300 (USAF) combines environmental serviceability and reliability requirements. The environmental requirements include:

- 1) Continuous operation at temperature extremes -65° and 460° F.
- 2) High voltage (1000 VAC RMS) capabilities at high altitudes (110,000 ft).
- 3) Oil, fuel, and moisture resistance.
- 4) Corrosion resistance.
- 5) Resistance to vibration and shock encountered in aircraft missiles.

Materials and techniques used to produce connectors that will meet the specified environmental serviceability and reliability requirements are detailed and illustrated.

68. O'Connell, J. A., Dr.  
APPLICATIONS OF INORGANIC AND ORGANIC THICK  
FILMS IN ELECTRONIC EQUIPMENT, Electronic Components  
Conference, 1966, Washington, D. C., pp. 238-250.

This paper describes the application of inorganic screen-printed "thick film" technology to a new microminiaturized five gc microwave transmitter-receiver as well as the application of completely novel organic thick film through-hole plated interconnection materials to the packaging of microelectronic equipments.

69. Peluso, R. F.  
A NONDESTRUCTIVE TEST METHOD FOR PROCESS CONTROL  
OF CROSS-WIRE RESISTANCE WELDS, M-63-114, Eighth  
Symposium of the Welded Electronic Packaging Association,  
Syracuse, New York, June 1963, 22 pp.

The primary purpose of this study was to establish the relation between weld-thickness measurement and wsec energy input at constant electrode force. Tests, conducted on welds of

nickel, kovar, and domet wire to nickel wire and ribbon, indicate a definite and reproducible relationship between thickness measurement and weld energy input. This relationship permits periodic checking of weld machine setup and a nondestructive process control of production welds. The system shows definite advantages over current methods.

70. Perl, M.

INSULATED WIRE WELDING PROCESS, Eighth Symposium of the Welded Electronic Packaging Association, Syracuse, New York, 20 June 1963, 12 pp.

In assembling electronic equipment comprised of welded modules, the simplest interconnection method is the mounting of modules on a prefabricated board and the welding of module leads with continuous point-to-point insulated wiring. A satisfactory method was developed for making resistance-welded connections through the wire insulation, displacing the insulation material by pressure of the welding electrodes. Sufficient bare wire is exposed during the welding process so that metal-to-metal contact between the electrodes is achieved. After studies of a number of insulation materials, it was determined that irradiated thermally-stabilized polyolefin insulation offered the desired characteristics. The process has been used during the past year in several electronic equipment packages and adapted for use as part of a semi-automated electronic packaging design technique.

71. Pfluger, A. R. and Maas, P. M.

LASER BEAM WELDING ELECTRONIC-COMPONENT LEADS, Welding Research Supplement, June 1965, pp. 264-s-269-s.

The basic objective of this study was to determine whether fusion welds could be made utilizing the light beam from a laser. The welds were to be such that they would be applicable to joining electronic-component leads. Several joint designs were investigated including cross-wire, cross-ribbon, wire-to-ribbon, and parallel wire joints. Most of the investigation was concerned with nickel wire and ribbon. Weld evaluation by visual and metallographic examination was performed and joint strength of parallel wire welds determined. Differences between laser welding and resistance cross-wire welding are discussed, and how these differences influence design of welded electronic circuitry is pointed out. It is suggested that other designs more suitable for laser welding be developed.

72. San Clemente, P. F.

A DISCUSSION OF THE OPTICAL LASER AS A MECHANISM FOR MICROWELDING, Eighth Symposium of the Welded Electric Packaging Association, Syracuse, New York, June 1963, 10 pp.

Laser beams, when focused, intensify and are capable of generating extremely high temperatures, making welding of most materials possible. The laser differs greatly from resistance welding processes in that power is generated outside the material rather than internally from resistance heating. The laser has the advantage of not requiring a vacuum and is capable of precise alignment and very small spot sizes; however, it does have the disadvantage, at present, of requiring intermittent operation.

73. Schaeffer, J. E.

WRAPPED-WIRE CONNECTIONS, Machine Design, Vol. 36, No. 12, 21 May 1964, pp. 202-208.

Consideration is given to the electrical, mechanical, and thermal properties which affect the performance of wrapped joint. From tests conducted by the Bell System, it was concluded that wrapped connections satisfy the mechanical security objectives in part, but not completely. They are more vulnerable to loosening by axial pull on the wire than soldered connections. Also, because wrapped connections are under tension, the wire tends to relax when heated. The only hardware involved in wire wrapping are the terminals themselves. These must be specified according to service conditions, design configuration, and manufacturing process.

74. Schumacher, J. H. and Lane, W. V.

PRINTED CIRCUIT CONNECTORS FOR MICROASSEMBLIES, IEEE Transactions on Parts, Materials, and Packaging, Vol. PMP-1, No. 1, June 1965, pp. s-371-s-380.

This paper discusses the development of the following microassembly connector designs:

- 1) A military quality receptacle for integration of the Micro-Circuit Module (MCM) into equipments.
- 2) A two-part 36-contact connector for an encapsulated microassembly.

- 3) A two-part 80-contact connector for an encapsulated microassembly.
- 4) A microwafer test socket for manufacturing inspection testing of the component 0.310-inch-square microwafers and for breadboarding microwafers in the development stages of an MCM.

These designs have been subjected to a wide range of environmental conditions encountered in military usage and have performed successfully. The connectors for the encapsulated microassemblies provide the hardware for a future approach in three-dimensional circuit packaging when surface protected microcircuit elements compatible with organic encapsulants become available.

75. Scott, I. D.  
WELDER OUTPUT PULSE MEASUREMENT AS A PROCESS CONTROL TECHNIQUE, Eighth Symposium of the Welded Electronic Packaging Association, Syracuse, New York, 20 June 1963, 8 pp.

Reduction of machine variables appears to be a fruitful field for investigation to find methods for improving control of the resistance welding process. Two welding machines, each indicating the same watt-seconds, could -- through an accumulation of variations in capacitance, voltmeter calibration, and output impedance -- deliver pulses entirely different in rise times, peak, duration, and total energy content; as a consequence, their weld producing effects would be drastically different. One approach to the problem of control is to measure and analyze the output pulse at the electrode tips. Any significant changes in the system will be detected by a corresponding change in the output pulse. Delivery of essentially identical pulses by each of a line of welding systems gives us assurance that the welding characteristics will be the same.

76. Singletary, B. H. and Little, C. T.  
PACKAGING OF AIRBORNE MULTIPLEXER-ENCODER PCM TELEMETRY SYSTEM, National Symposium on Space Electronics and Telemetry, Miami Beach, Florida, 1 October 1963, 9 pp.

This paper describes the design, construction, and environmental testing of the mechanical packaging used on an Airborne Multiplexer-Encoder PCM Telemetry System. Features of the package include the following:

- 1) Cast aluminum housing.
- 2) Internal shock and vibration isolators.
- 3) Fuel and oxidizer compatibility (UDMH and  $N_2 O_4$ ).
- 4) Welded circuitry.
- 5) Compression packaging.
- 6) Circuitry accessibility.

A compression packaged, foam encapsulated welded module was used. A key feature of this technique is that the entire module stack is placed under a compressive load of 8 to 10 psi at system assembly. This compression yields a semirigid, "solid mass" structure which possesses excellent shock and vibration attenuating characteristics.

77. Sinkler, S. D.  
 UNDERSTANDING FAILURE, Machine Design, Vol. 36, No. 12,  
 21 May 1964, pp. 184-189.

Besides cost, the major selection factors involve reliability, design configuration, performance in the field, production considerations, and maintainability. Reliability is one of the most controversial areas of all. Probably the safest approach to evaluating joint-life information is personal contact with the source. Making consistently good joints gets harder as components and joint areas get smaller and closer together. Troubles introduced by close spacing have both mechanical and thermal origins. Electrical connections fail mechanically in two ways; mechanical strength of the joint materials can sometimes be exceeded, and fatigue failure, a more common problem, occurs when a joint is repeatedly subjected to lower-level stressing. Thermal cycling is thought to have little effect on most electrical joints as long as steady-state temperature limits are not exceeded. However, joints in encapsulated assemblies can be overstressed under widely varying temperatures. Equipment exposed to the vacuum of outer space may experience low pressure difficulties.

78. Skow, N. A.  
 THIN COPPER-CLAD LAMINATES FOR MULTILAYER PRINTED  
 CIRCUIT BOARDS, IEEE Transactions on Parts, Materials, and  
 Packaging, Vol. PMP-1, No. 1, June 1965, pp. s-165-s-168.

This paper discusses the production of thin copper-clad laminates which are used in the manufacture of multilayer printed circuit boards. In addition to perfect copper and laminate

surfaces and freedom from internal voids, it is also necessary that the length and width of the copper-clad panel does not change during any of the fabrication operations in making the printed circuit. Electrically, it is important that the thin laminate has excellent dielectric strength, dielectric constant, and surface resistance. Mechanically, it is necessary that the material be strong, well bonded to the copper, and that the bond not be weakened by trichloroethylene vapors, etching solutions, soldering operations or shearing, sawing, drilling, or punching.

79. Stucki, F. F., Fuller, W. D., and Carpenter, R. D.  
MEASUREMENT OF INTERNAL STRESSES IN ENCAPSULATED  
ELECTRONIC MODULES, IEEE Transactions on Parts,  
Materials, and Packaging, Vol. PMP-1, No. 1, June 1965,  
pp. s-178-s-185.

A hydrostatically pressure sensitive transducer has been used to measure environmentally induced stresses in encapsulated electronic modules. Such measurements for a few encapsulants have shown large changes in internal stresses with small changes in ambient temperature, a shift in the stress transition range with formulation variations and changes in stress magnitude with component density in an electronic module. A change in stress can result in degradation of electronic circuit performance, if the change in the parameters of pressure sensitive components cannot be tolerated. Conversely, these temperature-induced stresses may be used deliberately to change component values for a desirable circuit characteristic. The stress distribution in an encapsulated module can only be roughly anticipated from measurements made with sample materials.

80. Thorn, R. P.  
BUILT-IN DAMPING CONTROLLING VIBRATION WITH  
INTEGRALLY DAMPED SHEET LAMINATES, Machine Design,  
Vol. 37, No. 27, 25 November 1965, pp. 174-179.

In determining the motion of a structure in response to vibration, three properties of the structure (mass, stiffness, and damping) are important. Normally, there are three approaches which may be taken in designing systems to control resonant response:



- 1) Detune the system.
- 2) Ruggedize the system.
- 3) Damp the system.

Practicing damping treatments generally fall into two separate classes or types; unconstrained or constrained-layer damping. Two-ply laminates consist of a base member used only for structural characteristics, and a damping layer used only for damping. This is called an unconstrained, additive, or free damping treatment. The second type of damping treatment is integral or constrained-layer damping. This method of construction allows a more efficient use of the damping material and provides a composite structural integrity that is not possible using the unconstrained approach.

81. Thorn, R. P.  
BUILT-IN DAMPING CONTROLLING VIBRATION AND  
INTEGRALLY DAMPED SHEET LAMINATES, Machine Design,  
Vol. 37, No. 28, 9 December 1965, pp. 166-171.

Loss factor, characteristic mode value, and frequency parameter of any damped laminate are closely interrelated. One factor not yet considered in the mode number,  $n$ , which describes two things: the mode shape or the manner in which the beam or plate is vibrating, and fixity or how the beam or plate is fixed or held. Mode shape is determined by the type of structure, how it is held, and which mode is being excited. Both beams and plates exhibit a variety of patterns or envelopes of vibration. These represent the natural frequencies of the structural member. It is not possible to state a hard-and-fast step-by-step procedure for designing structural elements of damped laminates, because the known and unknown quantities vary from one problem to another. However, a typical order of determination is as follows:

- 1) Controlling dimension.
- 2) Vibration mode number.
- 3) Characteristic mode value.
- 4) Frequency parameter.
- 5) Composite loss factor.
- 6) Resonant transmissibility.
- 7) Resonant frequency.

82. Uphouse, S. C.  
SELF-CONTAINED ELECTRONICS FOR NAVIGATIONAL  
INSTRUMENTS, Electronic Components Conference, 1966,  
Washington, D. C. , pp.269-280.

This paper discusses the interfacing of a miniature sensor element and self-keying packaging concepts used for integrating the electrical and mechanical elements into a truly symbiotic package. Unique circuit concepts are discussed and related to the multicircuit devices used on the hybrid thin-film circuit modules. To provide for module level repairability and efficiently package the rigid substrates into a cylindrical volume, a stacked assembly was used. In conjunction with the package design, it was necessary to devise and incorporate into the assembly sequence an intermodule wiring scheme.

83. U.S. Naval Ordnance Laboratory, White Oak, Maryland  
PROPERTIES OF COMMERCIALY AVAILABLE ENCAPSULATING COMPOUNDS by V. Steele and H. E. Mathews, 5 December 1960, NAVWEPS Report No. 7253, AD 251911 (Unclassified Report).

Twenty-nine commercially available encapsulating compounds were surveyed for application in naval ordnance. Recommended materials include five epoxy resins, three polyurethane foams, and two elastomers. Unfilled epoxy resins are generally unsuitable for encapsulation of ordnance exposed to large temperature differentials. Since all encapsulating compounds have limitations, selection of a material depends upon those criteria determined as most important for adequate performance of the component to be encapsulated. The advantages and limitations of various materials, recommended cure cycles, and commercial suppliers are included to assist the engineer in the selection and use of these encapsulating compounds.

84. Vondracek, C. H.  
INORGANIC POTTING COMPOUNDS FOR HIGH TEMPERATURES, Materials in Design Engineering, Vol. 60, No. 7, December 1964, pp. 100-103.

Many new inorganic potting materials have been developed for electrical components operating at temperatures of 500°C and above. However, these materials are not a cure-all for high temperature use, and their processing characteristics

such as fluidity, pot life, linear shrinkage, and water absorption and strength, and weight properties also have to be evaluated carefully. A list of many of the important inorganic potting compounds and their basic compositions is given.

85. Wells, F.  
CRIMPED CONNECTIONS, Machine Design, Vol. 36, No. 12,  
21 May 1964, pp. 196-201.

Crimped connections provide a uniform, gas-tight, metal-to-metal bond for stranded or solid wire without requiring application of heat or use of an intermediary material. Because metals are subject to creep or cold flow, crimping pressure must be applied to take advantage of the wire's tendency to expand after volumetric confinement, thus forming a tight mechanical connection. Crimped connections are purposely designed to approach, but not to exceed, tensile strength of the wire. Crimped connections are designed to withstand vibration and shock by dispersing stress concentrations through use of a gradual transition from barrel end to wire. Crimps have extremely low electrical resistance because of true metal-to-metal connection. Because the metal mass of the terminal provides additional heat-dissipation capacity, temperature and resistance are lower than those of the wire. Terminal material governs corrosion resistance. As long as mechanical requirements for making a crimped joint can be met by a material, terminals can be made from it. Specifications for terminals and wire must be geared to electrical and material properties.

86. Zglenicki, C.  
FOR A COOL WELD, TRY ULTRASONIC WELDING, Product Engineering, Vol. 36, No. 4, 15 February 1965, pp. 87-91.

Ultrasonic welding is compared to fusion, electron beam, resistance, and cold pressure welding. In many cases, ultrasonic welding works where another welding method may not. Suggestions are given for consideration when designing for ultrasonic welding.

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## Appendix C

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13. ABSTRACT This report reviews a survey of 17 industries on current techniques for packaging electronic equipment. Subjects covered include module configuration, package configuration, package housing, interconnection techniques, and potting compounds. The specific reports of each brief interview are contained in Appendix A of the report. Appendix B updates a previous bibliography for electronic packaging published in RSIC-534, entitled "Electronic Packaging: A Bibliography," dated March 1966. A listing of companies visited is included in the Foreword.  Information provided is a review of electronic packaging techniques ranging from the mounting of parts (discrete or integrated circuit) to a complete "black box." Module configurations discussed include planar printed-circuit boards, "stick" modules, cordwood, mylar tapes for part mounting, and variations of these. Package configurations have been aimed at reducing the number of layers in multilayer printed-circuit boards. Techniques include book type modules interleaving printed-circuit boards, slotted guides in housings, and precompressed stacks of printed-circuit board assemblies. The package housings may be cast, dip brazed, automatically milled from solid stock, or light sheet metal covers. Many types of interconnection techniques are in use including multilayer circuitry other than conventional printed-circuit boards. Eyelets and (Continued on Page 132)		

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plated-through holes are usually reinforced by filling, redundancy, etc. No great variations in potting methods were noted except for radio frequency modules. However, problems of nonuniform density were indicated.

It is apparent that no one approach is a panacea for all packaging requirements. Each piece of equipment must be analyzed (along with the manufacturer's capabilities) and the most appropriate technique selected.

RSIC-614

N/67-19037

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SUBJECT: Errata for RSIC-614, Title: Industrial Survey of Electronic Packaging

TO: Recipients of Subject Report

It is requested that the following changes be made in your copy of the subject report.

1) All figures cited under a specific company were provided by courtesy of that company.

2) Page iii and page 42, Motorola should be listed as Motorola, Inc., Aerospace Center, Scottsdale, Arizona.

3) Page iii and page 55, Philco should be listed as Philco-Ford Corporation, Space Re-Entry Systems Division.

4) Page 13, fourth paragraph, second line, ZYCON, trade name for a Chemtronic spray.

5) Page 14, paragraph 2, last line, "Uniform center coating" should read "uniform solder coating."

6) Page 55, fourth paragraph, second line should read "... as the Apollo Lunar Surface Program (ALSEP), subsystems for Mariner/Mars 69 and Pioneer C & D ..."

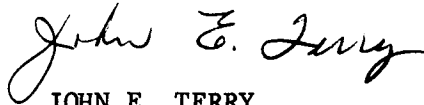
7) Page 56, first paragraph, tenth line, "solid aluminum" should be "solid magnesium."

8) Page 62, second paragraph should read, "The printed-circuit boards thus completed are compressed into a stack between radial-ribbed aluminum end plates and held with a center-through bolt or by the sides of the housing. A third approach is to suspend the stack within a metal housing on rubber vibration isolators which provide a "floating" arrangement for the stack."

9) Page 62, fourth paragraph, fifth line, "SATURN Block 2" should read "APOLLO, Block 2", seventh line, "APOLLO Block 2" should read "APOLLO Block 1."

10) Page 66, first paragraph, last seven lines starting with "Twenty of these ...," should be deleted. (Note: Prototype work is an exploratory laboratory study and the ratios mentioned have not been verified in final system application.)

11) Page 14, first paragraph, sixth line, "glass-elastometric" delete, "glass."

A handwritten signature in cursive script, reading "John E. Terry".

JOHN E. TERRY  
Acting Chief, Research Branch  
Redstone Scientific Information Center